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INSULATING BACKFILL FOR SHALLOW BURIED WATERMAINS

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Innovative Housing Grants Program

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INSULATING BACKFILL FOR SHALLOW BURIED WATERMAINS

January 1991

Prepared by:

W.H. Dilger, PhD., P. Eng.
The University of Calgary
for Consolidated Concrete Ltd.

The views and conclusions expressed and the recommendations made in this report are entirely those of the authors and should not be construed as expressing the opinions of Alberta Municipal Affairs.

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FOREWORD

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Innovative Housing Grants Program
Alberta Municipal Affairs
Housing Division
Research and Technical Support
16th Floor, CityCentre
10155 - 102 Street
Edmonton, Alberta
T5J 4L4

Telephone: (403) 427-8150

TABLE OF CONTENTS

Page No.

LIST OF TABLES iii
LIST OF FIGURES iii
EXECUTIVE SUMMARY vi
1.0 INTRODUCTION 1
    1.1 General 1
    1.2 Related Research 2
    1.3 Scope 4
    1.4 Organization of the Report 5
2.0 APPROACH 6
    2.1 Work Plan 6
    2.2 Facilities 6
        2.2.1 Description of Test Trenches 7
    2.3 Methodology 10
    2.4 Material Properties 11
    2.5 Basis Of Original Design 12
3.0 MEASUREMENTS IN WINTER - 1989/90 15
4.0 ANALYSIS AND EVALUATION 20
    4.1 Current Calgary Data and Comparison with 1988-1989 Data 20
    4.2 Description of Test Results 22
    4.3 Evaluation 37
    4.4 Comparison with Edmonton Data 38
5.0 CONCLUSIONS 39
    5.1 Trench Design 39
    5.2 Other Considerations 40
6.0 REFERENCES 41

TABLE OF CONTENTS (cont'd)

Page No.

Appendix A: Description of Tests 42 to 56
Appendix B: Measurements 57 to 68
Appendix C: Material Properties 69 to 79

LIST OF TABLES

			Page No.
Table	3.1	1980-1990 Test Trench Data for Granulite	16
Table	3.2	1988-1989 Test Trench data for Granulite	18
Table	4.1	Summary of Average Test Values of 1988/89 and 1989/90 Test Trench Data	21

LIST OF FIGURES

				Page No.
Figure	2.1	Proposed Configuration for Insulation of Water Main for Calgary Climatic Conditions		14
	4.1	Thermal Conductivity of Granulite vs Time	Test 1	25
	4.2	Thermal Conductivity of Granulite vs Time	Test 2	26
	4.3	Thermal Conductivity of Granulite vs Time	Test 3	27
	4.4	Thermal Conductivity of Granulite vs Time	Test 5	28
	4.5	Thermal Conductivity of Granulite vs Time	Test 6	29
	4.6	Thermal Conductivity of Granulite vs Time	Test 8.1	30
	4.7	Thermal Conductivity of Soil	Test 8.2	31
	4.8	Thermal Conductivity of Granulite	Test 8.3	32
	4.9	Thermal Conductivity of Granulite	Test 9	33
	4.10	Thermal Conductivity of Granulite	Test 11	34
	4.11	Thermal Conductivity of Insulcrete	Test 12	35
	4.12	Summary of Thermal Conductivity Data of Thawed Granulite		36

LIST OF TABLES
OF THE APPENDICES

Page No.

APPENDIX B

Table B.1 Thermocouples & Conductivity Probe Information 56

APPENDIX C

Table C.1 Thermal Conductivity & Moisture Content of Expanded Shale (Unfrozen) Stockpile Tests 75

Table C.2 Thermal Conductivity of Expanded Shale, Laboratory Tests 76

Table C.3 Young's Modulus and Coefficient of Volume Compressibility 77

Table C.4 Mix Proportions of Insulating Fillcrete 77

Table C.5 Geotechnical Data for Manchester Test Site 78

Table C.6 Geotechnical Data for Forest Lawn Test Site 79

LIST OF FIGURES OF THE APPENDICES

Page No.

APPENDIX A

Figure A.1 Layout of Tests at Manchester Site 46
A.2 Section through Test 1 47
A.3 Section through Test 2 47
A.4 Section through Test 3 48
A.5 Section through Test 4 48
A.6 Section through Test 5 49
A.7 Section through Test 6 49
A.8 Section through Test 7 50
A.9 Section through Test 8 51
A.10 Section through Test 9 52
A.11 Section through Test 10 53
A.12 Layout of Test at Forest Lawn Site 54
A.13 Section through Test 11 55
A.14 Section through Test 12 55
A.15 Proposed Configuration for Insulation of Watermain in Coarse Grained Soil for Calgary Conditions 56

APPENDIX B

Figure B.1 Detail About Installation of Thermocouples 65
B.2 Thermocouple Embedded in Copper Tube 66
B.3 Assembly of Thermocouples and Thermal Conductivity Probe Ready for Installation 66
B.4 Thermoprobe Schematic 67
B.5 Installed Tube for Moisture Content Measurements Complete with Top Box 68

APPENDIX C

Figure C.1 Grain Size Distribution 73

EXECUTIVE SUMMARY

INTRODUCTION

The depth of soil cover over buried water pipelines in the City of Calgary as well as any northern urban area, is dictated by the depth of frost penetration in the local soils during the winter months.

Until recently, the design criteria used by the City of Calgary Waterworks Department required a minimum depth of cover to the vipeline of 2.7 metres (9 feet) in clay soils and 3.3 metres (11 feet) in gravel soils. Installation of pipes and repair of broken pipes in such deep trenches is expensive, particularly in winter months when soil is frozen.

In 1988, a research program was launched with the objective of investigating the effectiveness of Granulite, a lightweight, insulating aggregate, used as an insulating backfill in watermain trenches, thus allowing the installation of water pipelines in much shallower trenches.

Granulite is a lightweight, granular material manufactured in rotary kilns from natural clay or shale. In appropriate circumstances the insulating value of the Granulite is many times greater than that of natural soils. Granulite, being a ceramic material, has relatively high strength, is chemically stable and environmentally safe. Similar materials have been used for this purpose in many European countries.

The original test program was conducted over the winter of 1988-1989 and consisted of the construction and instrumentation of twelve test trenches. Ten test trenches were located in the City of Calgary - Manchester Yard, in gravel soils and two trenches were located at the City Recycle Yard in Forest Lawn, where the local soil is a wet clay. Frost penetration measurements were made and thermal properties of the Granulite and backfill materials were established. The results are documented in a report entitled "Frost Protection of Underground Water Pipes", dated July 1989.

The program was carried out with the participation of the City of Calgary Waterworks personnel; Dr. W. H. Dilger, P. Eng., of the University of Calgary; Dr. L. E. Goodrich, Senior Researcher at the National Research Council Canada; Consolidated Concrete Limited, the manufacturer of Granulite; and M. Pildysh, P. Eng., of Pildysh and Associates Consultants Ltd.

Based on the original research data, a trench design utilizing Granulite insulating backfill was developed, allowing installation of watermains with only 2.1 metres (7 feet) of cover above the centre line of the pipe, in both the gravelly and clay soils encountered in Calgary. In 1989, the City of Calgary adopted the recommended trench design for the on-going watermain replacement program. Since then, this shallow trench method of construction has been used for replacement watermains installed by city work crews.

SCOPE AND FOCUS OF CURRENT PROGRAM (1989 - 1990)

The researchers responsible for the 1988-1989 program felt that the resultant trench design, as cost effective as it was reported to be, might be somewhat conservative. In order to determine the long term stability of the thermal properties of Granulite, when buried in a trench, and to assess the potential for optimizing the trench design by minimizing the required extent of Granulite further test data on the thermal properties and moisture condition of Granulite were required. This test program was developed to obtain the additional information and permit further evaluation of the original design.

Nine of the original trenches were equipped with permanent thermal conductivity probes and standpipes to facilitate measuring moisture content of the Granulite after burial over a long term. In analysing the new data obtained in the winter of 1989-1990, comparisons were made with data from the original test program and data obtained from a similar test program in Edmonton during the same time period. The new data was evaluated in relation to the original design parameters used for the recommended trench configuration for the Calgary area.

APPROACH

The project was undertaken in three phases. In Phase I, five sets of measurements of thermal conductivity, moisture content and temperature of Granulite were taken. In Phase II, the new test readings were analysed and compared with information obtained from the 1988/89 program. The new data sets were also compared with test results obtained from the similar project conducted in the City of Edmonton during the same winter season. In Phase III, the effects of the 1989/90 values of thermal conductivity were evaluated in relation to the parameters used in preparing the Calgary trench design. Final conclusions were then drawn.

CONCLUSIONS

It has been most useful to have a "second look" at the significant thermal characteristics of Granulite after one year of burial under actual operating conditions. The results of this testing program have shown that Granulite maintains a fairly constant moisture content and thermal conductivity values in trench conditions, over a long term.

The stability of these thermal parameters has indicated that no change in the design factors used to produce the original trench cross-section is warranted. Thus, the original trench design has been confirmed as valid for Calgary winter conditions.

These conclusions provide support for the general concept of narrower, shallower trenches for the burial of watermains insulated against frost by Granulite backfill. In the case of the City of Calgary, reduced burial depth in the order of 0.6 to 1.2 metres, has been made possible by insulating the watermains. This construction feature makes maintenance of the system faster, more convenient and less expensive, particularly in winter months.

Granulite offers the designer of underground utility systems the opportunity to modify frost penetration patterns, thus providing trouble free performance of the utility, often at reduced initial construction costs.

1.0 INTRODUCTION

1.1 General

The climatic conditions in Alberta, as well as much of the rest of Canada, make it necessary to bury water distribution pipes quite deep in order to prevent freezing. The depth of burial depends on the depth of frost penetration in a given area. This, in turn, depends on the anticipated severity of winter weather, the local soil conditions and construction practice. The City of Calgary specifications require a depth of 2.70 metres and 3.30 metres in clay and gravel soils respectively.

Installation and maintenance of water pipes in deep trenches is expensive, especially in winter when the soil is frozen. In addition, deep trenches increase the risk of cave-ins and, therefore, have to be heavily shored in order to ensure safety of the workers.

Water pipes can be safely installed at a reduced depth if the frost penetration is reduced by backfilling the pipe with a material which has insulating values higher than those of common backfill. A lightweight aggregate material called "Granulite", manufactured in Calgary and Edmonton by Consolidated Concrete Ltd., has been found to be a practical and economical insulating backfill material for shallower watermains in the City of Calgary.

Granulite is manufactured from natural clay in Edmonton and natural shale in Calgary, in rotary kilns, at temperatures of 1100^{O} Celsius. Cells formed by the expanding gases during the process, produce a hard, porous, granular material having a bulk density of 700 to 900 kg per cubic metre. The resultant product is a structurally sound, environmentally safe, cellular aggregate. In the past, this material was mainly used as aggregate for lightweight concrete. However, another important quality of the material has been determined - its thermal conductivity is only 25%-30% of that of conventional soil.

These properties make Granulite ideally suited as insulating fill in geotechnical applications, such as backfill for shallow water pipes.

Other possible applications of Granulite as insulating fill include protection of shallow foundations and road pavements in frost susceptible soil conditions where frost heave control is required. However, this project was concerned with watermain construction only.

1.2 Related Research

The use of lightweight aggregate materials, similar to Granulite, for frost protection of water pipes and other structures is well developed in Northern Europe and the USSR. Extensive technical information exists on the geotechnical and thermal properties of various lightweight aggregate materials manufactured around the world.

However, due to the specific qualities of raw materials, as well as differences in the manufacturing processes, each lightweight aggregate has its own physical properties, which must be determined by physical testing. The main characteristics affecting the insulating value of lightweight aggregate are thermal conductivity and moisture content.

Initial laboratory studies of Granulite (References 1 and 2) established its physical properties. Subsequently, field tests were performed on Granulite manufactured in both Calgary and Edmonton.

The Calgary Granulite was tested by the City of Calgary, Waterworks Division, and Consolidated Concrete Ltd., in 12 test trenches of various configurations installed in Calgary over the 1988-89 winter. The results were documented in a 1989 report entitled "Frost Protection of Underground Water Pipes", by W.H. Dilger, Ph.D., P. Eng. of the University of Calgary and L.E. Goodrich, Ph.D. of the National Research Council, Institute for Research in Construction (Reference 3).

The tests resulted in a trench design which significantly reduced the required depth of watermain installation in Calgary to 2.1 metres, provided the pipe trench was backfilled with a prescribed configuration of Granulite and common backfill. The shallower depth requirements also permitted a narrower trench design. The City of Calgary utilized Granulite insulation and the shallow trench construction method with their own construction crews during the summer of 1989 and in all watermain replacements beneath paved roadways during their entire 1990 construction program. This work was subjected to detailed, comparative cost studies by the City of Calgary Waterworks Division. Cost savings of 10% to 20% were reported.

However, the authors of the original report felt the proposed Calgary trench design, as cost effective as it was understood to be, might still be somewhat conservative and possible improvements could be made through further testing and refinement of the data collected during the original test program.

Another field test program of Granulite manufactured in Edmonton, was conducted by Consolidated Concrete Limited in conjuction with the City of Edmonton, Construction Branch, during the winter of 1989-1990. This study, conducted by the same principal researchers as the Calgary study, consisted of six test trenches of varying configuration and backfill types. These were instrumented to allow measurement of ground temperatures at several depths, and thermal conductivity values of the backfill, in-situ soils and Granulite materials. At the time of writing, the final report of this work had not been issued.

1.3 Scope

The object of this project was to obtain further field data during the winter of 1989-90 at the test installations constructed in Calgary in 1988, with the additional objective of collection and evaluation of the additional data and refinement or verification of the original watermain trench design developed for Calgary. Another important objective of this project was to confirm the longer term stability of the thermal properties of Granulite.

The scope of work of this project included:

(a) Measurement of thermal conductivity and moisture content in nine of the twelve existing test trenches in the City of Calgary over the winter of 1989-90, using the equipment and methods utilized on these test trenches during the initial 1988-89 project;

(b) Analysis and evaluation of the collected data to compare it with the data collected during the initial tests, to establish trends and to modify or validate the original design of shallower buried watermains for the City of Calgary as proposed in 1989; and

(c) Comparison of these additional test results from Calgary with those obtained from the field test program conducted in Edmonton, Alberta, during the winter of 1989-1990.

The work focused on using the test results to confirm or modify the basis of a cost-effective utility trench design for the Calgary area. Shallower watermain installations in other Alberta locations may have equal potential as that realized in the Calgary area, by the use of Granulite insulating aggregate as backfill around the mains. However, this study was concerned only with Calgary installations, for the reason that watermain trench design is area-specific and depends on both soil and winter conditions in the area.

1.4 Organization of the Report

Data collection and presentation has been organized to compliment the original study and provide information on the longer term stability of Granulite characteristics and the effect on original trench design for the City of Calgary.

The present undertaking is described in relation to the original study, in Section 2 of this report. As background for the reader, the selection of the original design parameters and the geothermal studies leading to the original recommendations for an insulated watermain trench for Calgary conditions, have been presented.

Measurements during the winter of 1989-1990 have been reported, summarized and presented graphically in relation to the results obtained in the original study, for convenience of comparison. Presentation of data and discussion of the results will be found in Sections 3 and 4 of this report respectively. The conclusions reached on the basis of the present study related to the original trench design currently in use in the City of Calgary watermain construction program.

The conclusions reached on the basis of this additional study are given in Section 5 and are significant to the longer term understanding of the performance of Granulite.

2.0 APPROACH

2.1 Work Plan

The work was undertaken in three phases:

(1) Data Collection
(2) Analysis and Evaluation
(3) Final Report

All technical tasks of the project were undertaken by University of Calgary staff directed by Dr. Walter Dilger, Professor of Civil Engineering. Final review of the thermal conductivity data was carried out by Dr. Laurel Goodrich, Senior Researcher with the National Research Council Canada, as well as Mr. R. Saunders, M.Eng., P.Eng.,Senior Geotechnical Engineer with Geo-Engineering (M.S.T.) Ltd. of Calgary. Overall project management was provided by Mr. M. Pildysh, P.Eng., of Pildysh and Associates Consultants Ltd. All of the participants were involved in the project on behalf of Consolidated Concrete Limited, whose Project Coordinator was Mr. A. Priestley, P. Eng.

2.2 Facilities

Test trench installations for the original study were constructed in Calgary in the fall of 1988 at two sites, Manchester Waterworks Yard and Forest Lawn Soil Recycle Centre. Trenches 1 to 10 were located at the Manchester location where local soil was classified as dry, sandy gravel. Trenches 11 and 12 were located in Forest Lawn where local soil was classified as typical wet clay. The test sites permitted the study of Granulite performance in two distinctly different soil conditions typical to the Calgary area.

The test trenches differed in the extent and configuration of Granulite fill, as well as backfill materials and separation layers (synthetic membranes and geotextiles). Details of the test trench installations are described briefly in the following section. Additional detail has been provided in Appendix "A".

Comparisons of Granulite properties with properties of other materials (a part of the original study) was not within the scope of work of this study. Therefore, the original test trenches which contained no Granulite (Test 4 - containing Styrofoam; Test 7 - containing an existing watermain; or Test 10 - a control section, contained no thermal conductivity probes) were not monitored in this study. The remaining test trenches, which were equipped with permanently installed thermal conductivity probes, thermocouples and standpipes, to allow the measurement of moisture content, were included.

The thermal conductivity probes were designed by the National Research Council Canada and manufactured by a specialty manufacturer in Ontario. The thermocouples were manufactured by the University of Calgary. Details of measuring devices and their installation are given in Appendix "B".

2.2.1 Description of Test Trenches

The description of the test trenches and the equipment installation pertaining to this study are briefly described below. Details of the layout of the two test sites (Manchester and Forest Lawn), together with details of the test trenches, are given in Appendix "A", Figures A.1 to A.14.

Test Trench 1 (Figure A.2)

Thermal conductivity probe number 1 was embedded in the middle of a 300mm thick layer of Granulite, at a depth of 1150mm below finished grade. The Granulite layer was wrapped in a single thickness of geotextile fabric and the trench backfilled with common fill.

Test Trench 2 (Figure A.3)

This trench was similar to trench number 1 except that Granulite was wrapped in a polyethylene sheet instead of geotextile fabric. Thermal conductivity probe number 2 was installed in the Granulite layer.

Test Trench 3 (Figure A.4)

This trench was similar to trench 1 except the backfill material was an imported clay instead of local sandy gravel. Thermal conductivity probe number 3 was installed in the Granulite layer.

Test Trench 4 (Figure A.5)

The dimensions of this trench were the same as trenches 1 to 3. However, the lower portion of the trench was backfilled with pea-gravel covered with a 76mm thick layer of Styrofoam HI-60. The trench was backfilled with common fill. No thermal conductivity probe was installed in this trench. This trench was not monitored during the study.

Test Trench 5 (Figure A.6)

This trench was 1800mm deep with a 400 to 600mm thick layer of Granulite at the bottom, covered with a geotextile fabric. The thermal conductivity probe was located at 1500mm below grade. The trench was backfilled with common fill.

Test Trench 6 (Figure A.7)

Trench 6 was the same as trench 5 except that no geotextile fabric was placed over the Granulite layer.

Test Trench 7 (Figure A.8)

Trench 7 was constructed around an existing watermain and, although instrumented to determine the temperature profile, no Granulite was placed and no thermal conductivity probe installed. This trench was not monitored during the current study.

Test Trench 8 (Figure A.9)

This trench was constructed to a depth of 2500mm to include an existing 200mm diameter watermain. Granulite was placed to a depth of 700mm above the pipe. Three thermal conductivity probes were installed in this trench: Probe 8.1 in the Granulite at the mid-level of the watermain, 2200mm below grade; Probe 8.2 at the same level in the adjacent, undisturbed soil; Probe 8.3 in the undisturbed soil at 1100mm below grade.

Road Test 9 (Figure A.10)

This test represented a road section with a 300mm thick layer of Granulite placed beneath 100mm of crushed gravel and a 200mm thick layer of asphaltic concrete. A thermal conductivity probe was installed at the centre of the Granulite layer, in the centre of the road area.

Control test 10 (Figure A.11)

This installation was simply an augered hole, to a depth of 3000mm, which served as a control section. It was instrumented to provide thermal profiles only and contained no Granulite. This installation was not monitored during the current study.

Test Trench 11 (Figure A.13)

This trench was constructed to a depth of 1750mm. A 500mm thick layer of Granulite was placed in the bottom, covered with a layer of polyethylene sheet. Thermal conductivity probe 11 was placed at the centre of the Granulite layer. The trench was backfilled with compacted clay.

Test Trench 12 (Figure A.14)

The size of this trench was the same as trench 11. The entire trench was backfilled with Insulating Fillcrete, a very low strength, no-fines, lightweight aggregate concrete. Thermal conductivity probe number 12 was installed in this trench.

2.3 Methodology

Thermal conductivity measurements were taken periodically throughout the winter months of 1989-1990. All thermal conductivity probes, previously installed in the original test trenches, were read on each occasion. The measurements included the temperature at the probe location, the thermal conductivity value of the Granulite or native soil surrounding the various probes and the moisture content of the Granulite. The probes were located where standpipes had been originally installed to permit readings using a nuclear probe.

Thermal conductivity was measured by a specially computerized monitor connected to the outlet of the thermal conductivity probe cable for the duration of the measurement. Each measurement on a probe required approximately 20 minutes. Repeat measurements, where required for verification, used different voltages. With the measurement of the thermal conductivity, the temperature of the soil/fill at the probe location was automatically recorded.

Moisture content measurements were carried out using a nuclear probe lowered into the permanently installed standpipes. The probe was lowered to the required depth and the reading taken on a digital screen. The probe was calibrated to give values of moisture content by volume. However, for thermal evaluation purposes, the moisture content as a percentage of the dry density of the Granulite or soil backfill was reported. Details of procedures used in taking temperature, thermal conductivity and moisture content readings are given in Appendix B.

2.4 Material Properties

The physical properties of Granulite were initially determined by test programs conducted for Consolidated Concrete Limited by the National Research Council Canada (Reference 1) and by EBA Engineering Consultants Limited (Reference 2). Subsequently, the field testing program of 1988-89 was conducted, resulting in the information on the field properties of Granulite. Detailed information obtained from these testing programs is given in Appendix C.

The results obtained from these tests were used to select design values for thermal conductivity and moisture content of Granulite. These were used in the one-dimensional thermal analysis performed by Dr. Goodrich at the N.R.C.C. Laboratory. The following design values were adopted for Granulite.

- Dry Unit Mass = 0.85 t/m^3
- Moisture Content = 17% by weight
- k thawed = 0.3 W/m°C
- k frozen = 0.3 W/m°C

Although lower values for thermal conductivity of coarse Granulite are achievable, a minimum value of k = 0.3 W/m°C was selected for conservative design use.

Granulite moisture content design value was selected to minimize the contribution of latent heat of moisture to the frost protection of the water main. This decision was based on the assumption that an increase in moisture content, even with a corresponding increase in "k", would make a positive contribution to the ultimate frost protection provided by the Granulite layer.

Note: Units of thermal conductivity, k, are defined as W/mK. The kelvin (K) unit of measurement is the Celsius degree based on absolute zero at zero K, the equivalent of -273.15°C. Thermal conductivity units have been shown interchangeably, in this report, as "W/mK" and "W/m°C".

2.5 Basis of Original Design

The data obtained from the original test in 1988/89 provided information on:

(a) temperature profiles of test trench and the depth of frost penetration.

(b) the thermal conductivity of the Granulite and the temperature at each probe location at the time of measurement.

(c) the moisture content of the Granulite at the time of the above measurements.

The temperature profiles in known materials provide data only for the calibration of the finite-element heat transfer model. This data is used in conjunction with the known Freezing Index, measured in negative-degree-days (Celsius), a measure of the severity of the winter weather. Having calibrated the model to produce temperature profiles similar to those measured in the field during a winter of known severity, a design can be prepared based on the selected Freezing Index. Information for computing the Freezing Index is available at local Environment Canada offices. The type and extent of backfill materials can be varied and the results checked with the model to ensure frost-free conditions at water main level under design winter conditions.

A one-dimensional finite-element heat transfer model was used along with the data obtained from the original field and laboratory tests to develop the water main frost protection design shown in Figure 2.1. The model allows for heat transfer by conduction, with inclusion of the solid-liquid phase change. Phase change is treated by a method that accurately models the displacement of the freeze-thaw boundary as a part of the solution process at each time-step by using a local adaptive grid scheme. The calculations assume the phase change occurs entirely at $0^{o}C$.

To conservatively model the buried water main geometry, heat transfer was assumed to occur in the vertical direction only, while heat advected by the water main was ignored. The ground was divided into several homogeneous layers in the following sequence:

Asphalt Surfacing
Trench Backfill (Sand)
Granulite
Dry, Coarse-Grained Soil (Native)

Calibration of the heat transfer model for the Calgary area had been satisfactorily carried out in 1989 based on temperature profiles determined during the test winter of 1988/89. Therefore, it had been concluded there was no need to obtain additional temperature data in the existing test trenches. Only a significant variation in the k-value of the Granulite would have had any effect on the trench configuration under the design winter conditions.

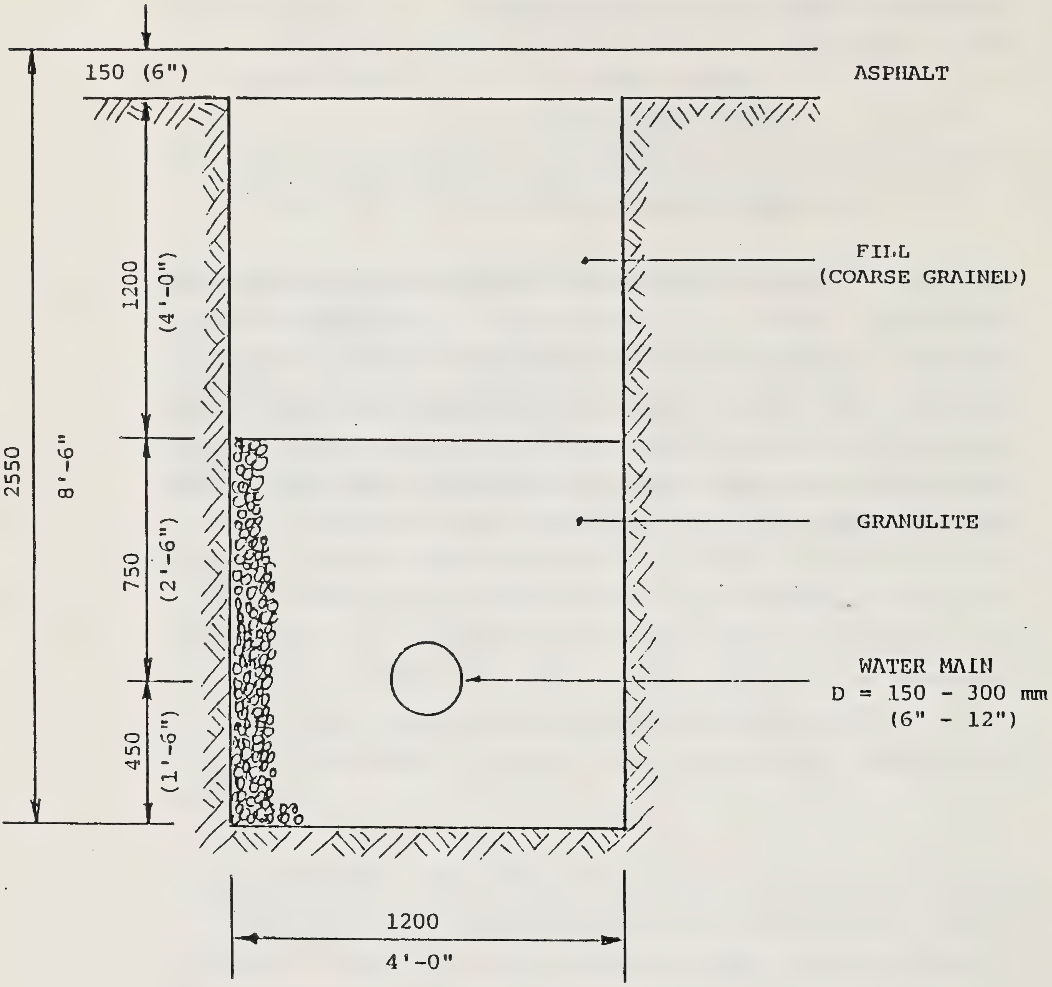


Figure 2.1 Proposed Configuration for Insulation of Water Main for CALGARY Climatic Conditions.

3.0 MEASUREMENTS IN WINTER 1989/90

In accordance with the scope of work for this project, as described in Section 1.3, the following measurements were made on the original test installations, during the winter months of 1989-1990:

- Thermal conductivity, k (W/m^{O}C)
- Moisture Content, % by weight
- Temperature, ^{O}C, at the probe location

Test measurements were made on the following dates:

December 19, 1989
January 30, 1990
March 14, 1990
April 5, 1990
May 7, 1990

An equipment failure on May 7, 1990 resulted in the loss of test data, producing some questionable results. These results have been omitted from further consideration in this test program.

All test measurements are recorded in Table 3.1, "1989-1990 Test Trench Data for Granulite".

Test Data from the original tests, recorded during the winter of 1988-1989, is shown in Table 3.2, "1988-1989 Test Trench Data for Granulite".

TABLE 3.1

1989 - 1990 TEST TRENCH DATA FOR GRANULITE

MC: Moisture Content, (% by Weight)
Temp: Temperature, (°C)
TC Probe: Thermal Conductivity, k, (W/mK)

DATE OF TEST		DEC19	JAN30	MAR14	APR 5
Test No.	(Depth (mm) of Moisture Reading) Test				
1	(1190)				
	MC	36.0%	35.8%	43.8%	36.4%
	Temp	2.6	0.7	-0.7	6.8
	TC Probe	0.40	0.37	0.47	0.41
2	(1190)				
	MC	25.0%	24.7%	25.7%	25.3%
	Temp	2.7	0.9	0.0	6.9
	TC Probe	0.40	0.38	(1)	0.44
3	(1190)				
	MC	(2)	27.6%	30.8%	30.4%
	Temp	2.6	0.7	0.2	6.9
	TC Probe	0.40	0.39	0.40	0.43
5	(1500)				
	MC	22.0%	22.6%	21.7%	24.4%
	Temp	5.3	2.8	1.2	7.4
	TC Probe	0.38	0.36	0.35	0.38
6	(1500)				
	MC	24.4%	23.6%	23.0%	25.1%
	Temp	5.5	2.9	1.1	7.5
	TC Probe	0.39	0.37	0.35	0.39
8	(2340)				
	MC	21.4%	(3)	20.8%	21.9%
	Temp 8.1 (Granulite)	5.6	4.0	2.4	2.7
	Temp 8.2 (Soil)	6.0	4.2	2.4	2.6
	Temp 8.3 (Soil)	1.2	0	-0.8	0
	TC Probe8.1	0.29	0.28	0.28	0.28
	TC Probe8.2	1.49	1.30	1.58	(4)
	TC probe8.3	1.54	1.42	1.35	1.37
9	(450)				
	MC	48.6%	(2)	(2)	(2)
	Temp	-3.7	-7.1	0.6	4.8
	TC Probe	0.34	0.36	0.32	0.38

TABLE 3.1 CONTINUED

11	(1550)				
	MC	38.4%	36.9%	40.3%	43.4%
	Temp	2.7	0.7	-0.5	-0.2
	TC Probe	0.42	0.39	(1)	(1)
12	MC (not measured in this trench)				
	Temp	3.9	1.6	0.3	0
	TC Probe	0.57	0.55	0.53	-
	Air Temp	-20.0	-27.1	+7.0	-3.3

NOTES:

(1) The missing values were recorded at temperatures near 0°C and are, for this reason, not usable.
(2) Tube filled with water.
(3) Top of tube frozen.
(4) Data lost.

TABLE 3.2

1988 - 1989 TEST TRENCH DATA FOR GRANULITE

MC: Moisture Content, (% by Weight)
Temp: Temperature, (oC)
TC Probe: Thermal Conductivity, k, (W/mK)

DATE OF TEST		NOV24	DEC7	DEC22	JAN5	JAN19	FEB2	FEB23	MAR16	APR6	APR27
Test No.	(Depth (mm) of Moisture Content Reading) Test										
1	(1190)										
	MC	26.8%	26.9%	26.5%	26.2%	26.9%	27.2%	27.5%	27.5%	29.0%	30.0%
	Temp	5.3	4.0	2.7	0.2	-1.0	-1.1	-3.0	-1.2	-0.1	8.6
	TC Probe	0.33	0.32	0.32	0.36	0.36	0.37	0.32	0.36	(1)	0.37
2	(1190)										
	MC	23.2%	23.4%	23.0%	23.3%	23.6%	23.8%	24.2%	24.6%	24.7%	24.3%
	Temp	5.7	4.5	3.0	0.4	-0.7	-0.7	-2.6	-1.0	0.0	8.6
	TC Probe	0.40	0.39	0.39	0.38	-	-	0.40	0.47	-	0.43
3	(1190)										
	MC	25.0%	24.4%	24.7%	25.5%	29.2%	28.1%	26.6%	27.6%	28.2%	28.2%
	Temp	5.6	4.3	2.7	0.8	-0.8	-0.8	-3.1	-1.8	-0.2	8.5
	TC Probe	0.34	0.38	0.30	0.36	-	-	0.42	-	-	0.44
5	(1500)										
	MC	21.3%	21.2%	21.5%	21.5%	22.7%	20.7%	21.0%	21.6%	23.3%	23.7%
	Temp	8.7	6.8	5.5	3.5	2.0	1.6	0.0	-1.9	0.5	8.1
	TC Probe	0.39	0.38	0.38	0.37	0.35	0.34	-	-	0.34	0.39
6	(1500)										
	MC	23.5%	23.9%	23.5%	23.3%	22.3%	22.5%	22.7%	22.9%	26.9%	24.9%
	Temp	8.7	6.8	5.5	3.5	2.0	1.5	-0.1	0.0	0.5	8.1
	TC Probe	0.39	0.38	0.38	0.37	0.35	0.34	-	-	0.34	0.39
8	(2340)										
	MC	19.9%	20.4%	20.0%	19.9%	20.1%	19.9%	20.1%	-	-	19.6%
	Temp 1	8.2	7.0	5.9	4.9	4.2	3.4	2.2	1.5	1.4	2.0
	Temp 2	8.3	7.0	6.1	5.0	4.1	3.5	2.1	1.4	1.3	2.0
	Temp 3	2.9	2.1	1.2	-0.5	-1.3	-2.1	-4.0	-3.4	0.9	0.7
	TC Probe 1	0.30	0.29	0.29	0.28	0.27	0.27	0.25	0.25	0.26	0.26
	TC Probe 2	1.33	1.35	1.36	1.33	1.29	1.30	1.25	1.24	1.13	1.22
	TC probe 3	1.27	1.26	1.28	-	-	-	1.23	1.29	-	-
9	(450)										
	MC	7.5%	7.7%	7.8%	8.8%	8.3%	7.9%	9.3%	8.4%	8.7%	9.3%
	Temp	2.7	1.9	-1.6	-2.0	-2.5	-14.5	-1.7	-3.3	5.5	7.2
	TC Probe	0.29	0.29	0.37	0.30	0.31	0.25	0.30	0.29	0.36	0.38
11	(1550)										
	MC	56.4%	34.2%	32.2%	31.2%	32.3%	29.8%	35.9%	36.6%	36.8%	60.9%
	Temp	5.5	3.8	2.6	1.8	0.8	0.0	-2.3	-1.8	-0.9	-0.4
	TC Probe	0.96(2)	0.46	0.45	0.43	0.39	0.35	0.32	0.31	-	-

TABLE 3.2 CONTINUED

12	MC (not measured in this trench)										
	Temp	7.1	5.0	3.7	2.3	1.7	1.1	-2.1	-0.5	-0.4	-0.3
	TC Probe	1.04(2)	0.56	0.54	0.53	0.52	0.51	0.50	-	-	-

Notes:

(1) The missing values were recorded at temperatures near 0°C and are, for this reason, not usable.

(2) Gravity drainage provided to Test Trenches 11 and 12 following this test reading.

4.0 ANALYSIS AND EVALUATION

4.1 Current Data and Comparison with 1988-89 Data

Current test data has been compiled in Table 3.1. Test data from the original tests recorded during the winter of 1988-1989, are shown in Table 3.2. A summary of average values of moisture content and "k", for each series of tests, is given in Tabel 4.1.

The results of all thermal conductivity tests at all thermal probe locations, for both winters 1988-1989 and 1989-1990, have been plotted in Figure 4.1 to Figure 4.11 to provide convenient detailed comparison. Values of temperature and moisture content for all tests are also shown.

Thermal and conductivity probes can only provide reliable results in conditions where the material properties are homogeneous over a zone of 100-200 mm around the probe. Melting of frozen moisture during the course of testing leads to meaningless results. For this reason, most of the data recorded at temperatures around the freezing point were discarded. Consistent results were obtained where the Granulite layer was either totally thawed or totally frozen when the measurements were recorded.

In addition to temperature, the moisture content (in percent by weight) is provided as measured by means of the hydroprobe on the same dates. In the following sections, Figures 4.1 to 4.11 are discussed in detail. In these figures the measurements between November 10, 1988 and April 27, 1989 represent the data collected during the original research project. The current study has produced new results which were recorded between December 19, 1989 and April 5, 1990. For brevity the units of thermal conductivity, k, which is measured in W/mK, have been omitted whenever k-values are given.

All the thermal conductivity test results have been plotted in Figure 4.12 as a function of the moisture content of Granulite.

TABLE 4.1

Summary of Average Test Values of 1988/89 and 1989/90 Test Trench Data

Moisture Content (% by Weight)
Thermal Conductivity, k, (W/mK)

	1988-1989 Test Data			1989-1990 Test Data (from Table 3.1)		
		Thermal Conductivity			Thermal Conductivity	
Test No.	Moisture Content	k Thawed	k Frozen	Moisture Content	k Thawed	k Frozen
1	27.4	0.34	0.35	36.1	0.39	0.47 (1)
2	23.8	0.40	0.43	25.2	0.41	- (4)
3	26.8	0.36	0.42	29.6	0.41	-
5	21.8	0.39	-	22.7	0.37	-
6	21.7	0.37	-	24.0	0.38	-
8.1 (2)	20.0	0.27	-	21.4	0.28	-
8.2	(3)	1.28	-	-	1.46	-
8.3	(3)	1.27	1.26	-	1.44	1.35
9	8.4	0.33	0.30	8.3	0.35	0.35
11	33.6	0.42	0.31	37.6	0.41	-
11	56.4	0.96	(Saturated Conditions)			
12	(5)	0.53	-	(5)	0.55	-

(1) Sample near saturation and temperature near 0^{o}C.

(2) Probe 8.1 in Granulite, Probes 8.2, 8.3 in undisturbed native soil. Moisture content measured in Granulite only.

(3) Data not measured (see Tables 3.1, 3.2).

(4) Missing values unreliable (see Tables 3.1, 3.2).

(5) Not measured in trench. Insulating Fillcrete backfill, not loose Granulite.

4.2 Description of Test Results

Configuration of test trenches and location of thermal conductivity probes are shown in Appendix "A", Figures A.1 to A.14.

Test 1 (Figure 4.1)

In this trench, the 1989/90 measurements of thermal conductivity indicated a slight increase in the value of k for thawed conditions with the average value of k being equal to 0.39 compared with 0.35 in 1988/89. The higher value can be explained by the higher moisture content in 1989/90.

On March 14, 1990, the value $k = 0.47$ was recorded at a temperature fractionally below $0^{o}C$. As previously stated in section 2.5, k-values recorded near $0^{o}C$ are questionable.

Test 2 (Figure 4.2)

The k-values recorded in 1989/90 compare well with those measured during the previous winter. The value observed on March 14, 1990 was discarded because the temperature was $0^{o}C$. It is noteworthy that the moisture content remained almost unchanged during the two winters observed.

Test 3 (Figure 4.3)

The 1989/90 k-values vary between 0.39 and 0.43 and compare well with the value of 0.43 recorded at the end of the original measurement program. The temperatures at the probe level were always positive and the moisture content was marginally higher than the original values.

Test 5 (Figure 4.4)

In the 1989/90 tests the frost did not penetrate to the probe level. The k-values varied between 0.35 and 0.38 and are similar to those originally measured in 1988/89. The moisture content recorded during the current test is essentially the same as the original values.

Test 6 (Figure 4.5)

The k-values, the temperatures and the moisture content data were almost the same for both test programs.

Test 8, Probe 8.1 (Figure 4.6)

The k-values measured in Granulite remained more or less constant at 0.28 during the 1989/90 measurements. The new values compared well with those recorded during the previous winter. The moisture content increased only slightly from an average of 20% in 1988/89 to 21.4% in the winter of 1989/90.

Test 8, Probe 8.2 (Figure 4.7)

The thermal conductivity values for the in-situ soil at 2200mm depth, recorded in 1989/90, are somewhat higher than those recorded the previous winter. The moisture content of the soil at this level was not measured. Since the average temperatures of all measurements in each set of measurements were closely the same, with no below zero readings, it can only be assumed that an increase in the moisture content of the natural soil had developed. Evaluation of k-values for native soils did not form a part of this study and these values are not needed for trench design.

Test 8, Probe 8-3 (Figure 4.8)

At a depth of 1100mm in native soil, the k-values showed an increase in value from 1988/89 to 1989/90. No moisture content readings were recorded at this elevation in native soil. The 1989/90 values were taken at temperatures close to 0^{O}C, thus exhibiting less consistency than those recorded in the previous winter, when the temperatures were significantly above or below 0^{O}C. These values were not needed for trench design.

Test 9, (Figure 4.9)

The test of the 1989/90 results indicated k-values were in the same range as those recorded previously. The moisture content of 48.6%, recorded on December 19, 1989 should be considered questionable. Subsequent attempts to record the moisture content were unsuccessful because of the presence of water in the tube.

Test 11 (Figure 4.10)

Only two of the four 1989/90 recorded k-values could be used because the temperature was fractionally below freezing during the other two measurements. The k-values of 0.42 and 0.39 are in line with those values measured during the original test period. The moisture content in 1989/90 was about the same as that recorded during the same period the year before.

Test 12 (Figure 4.11)

The 1989/90 k-values of Insulating Fillcrete, which lie between 0.53 and 0.57, are consistent with those of the previous winter which ranged between 0.50 and 0.56, after draining of the trench. No moisture contents were recorded for this location because no standpipe was installed in this trench. Insulating Fillcrete is not used in the proposed trench design.

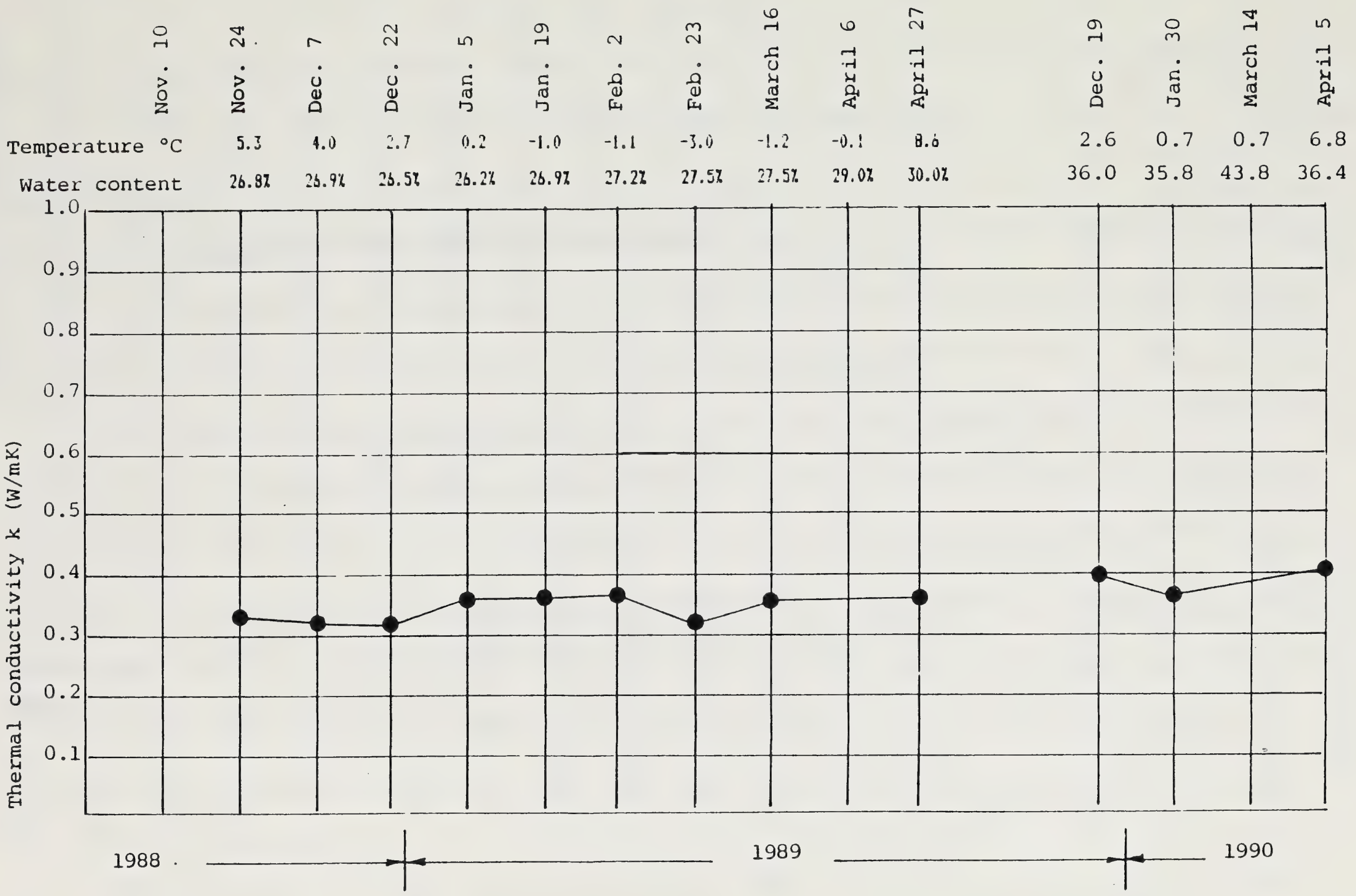


Fig. 4.1 Thermal conductivity of GRANULITE vs. time - Test 1

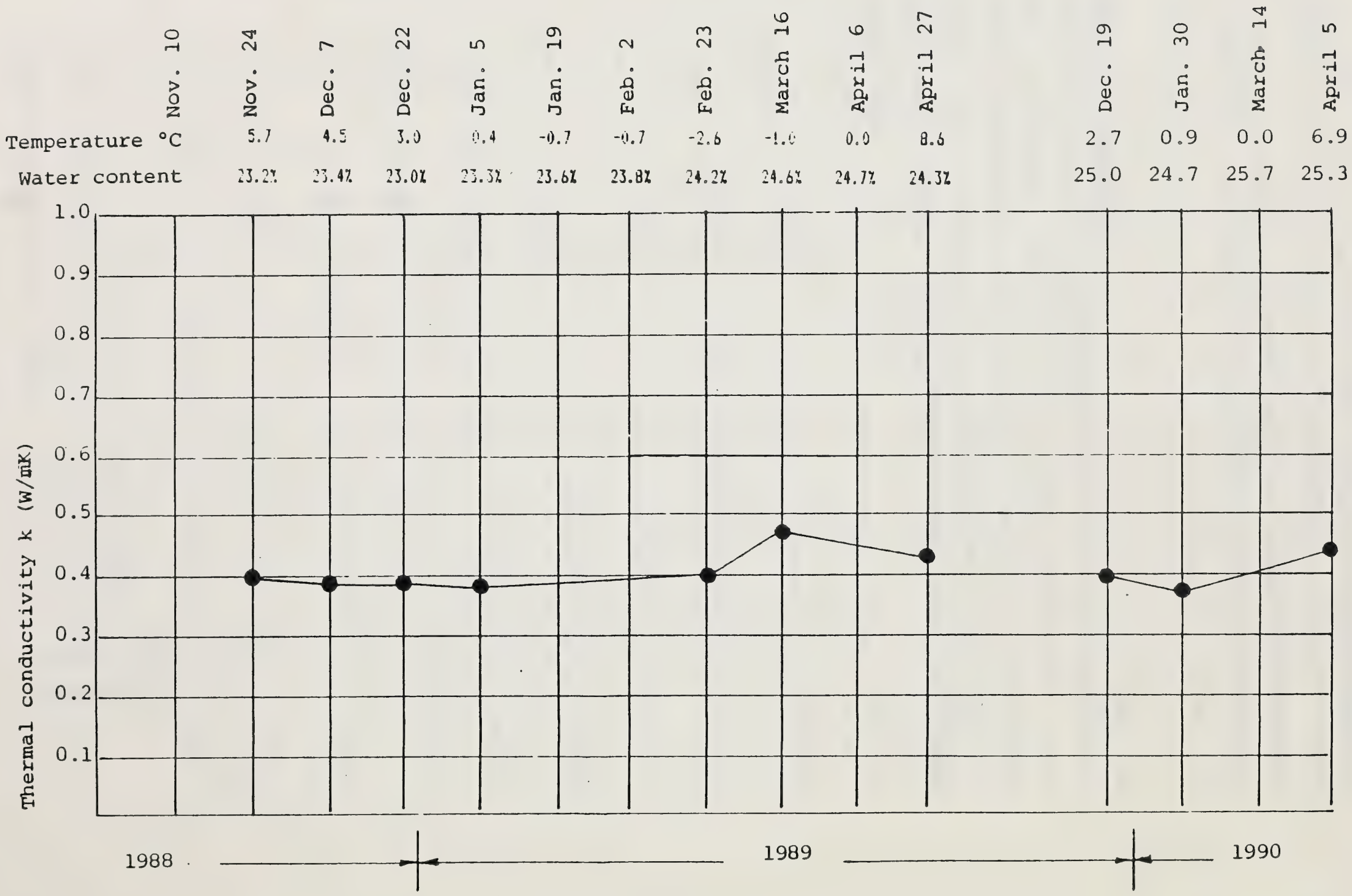


Fig. 4.2 Thermal conductivity of GRANULITE vs. time - Test 2

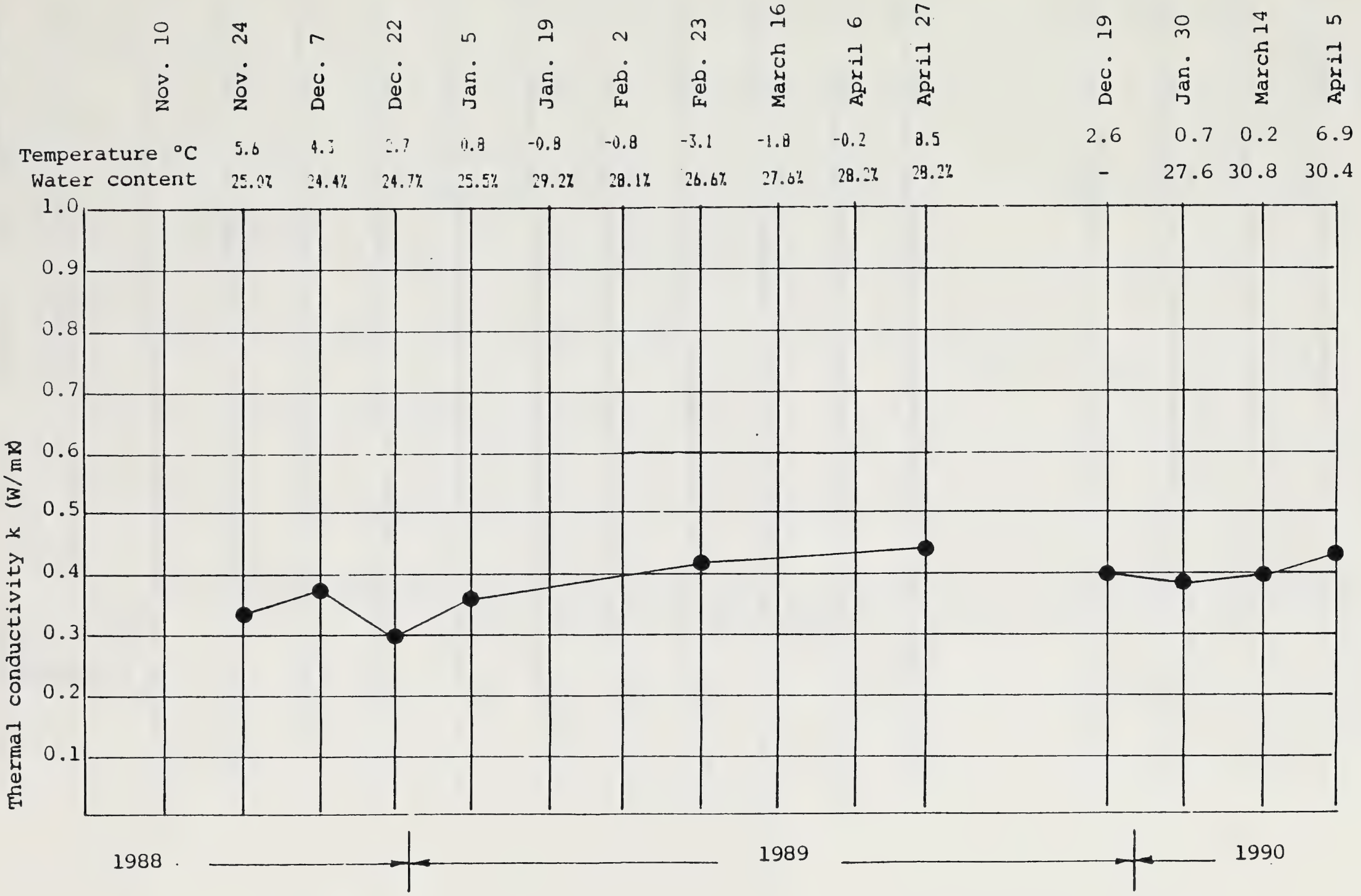


Fig. 4.3 Thermal conductivity of GRANULITE vs. time - Test 3

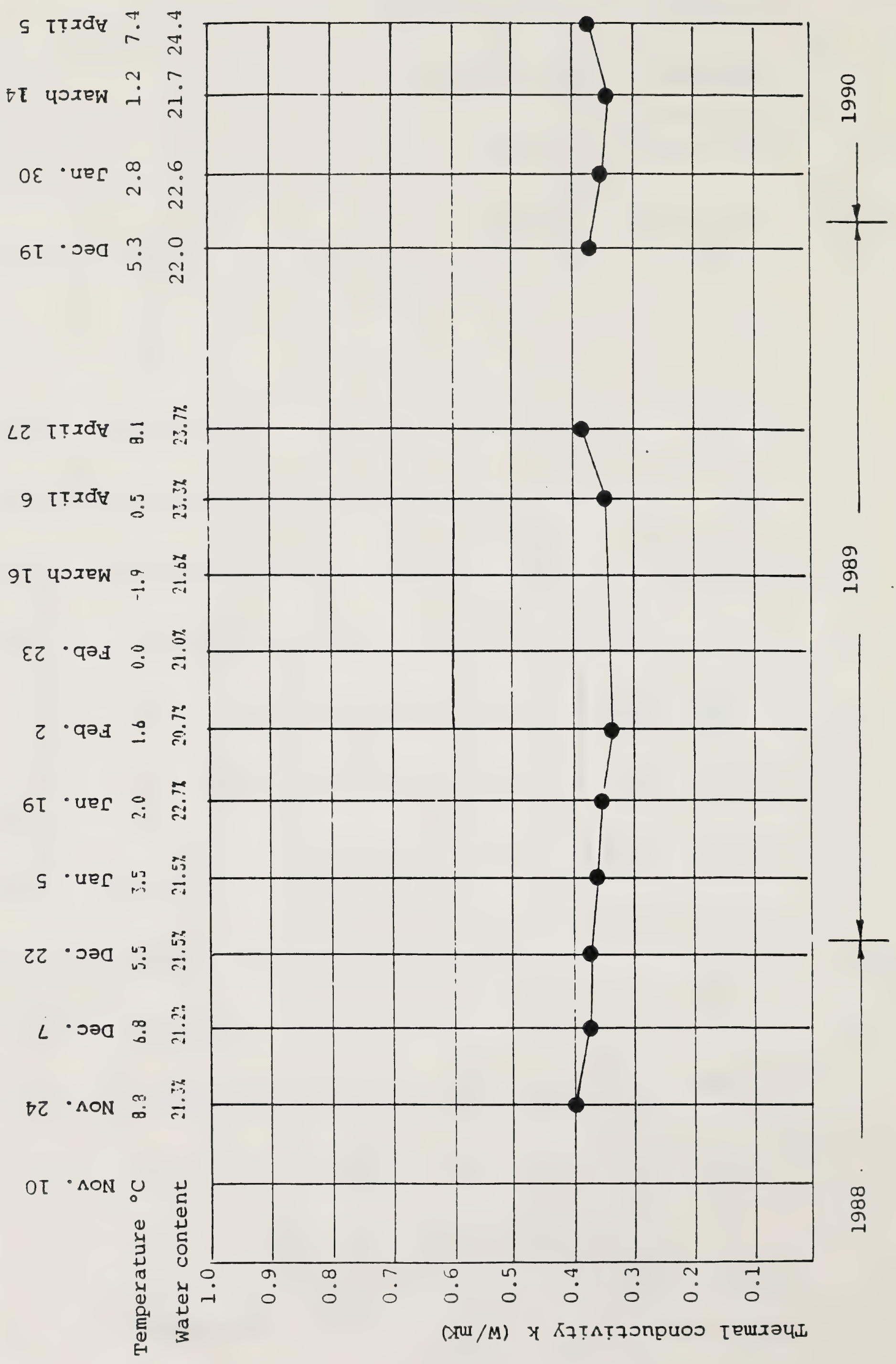


Fig. 4.4 Thermal conductivity of GRANULITE vs. time in Test 5

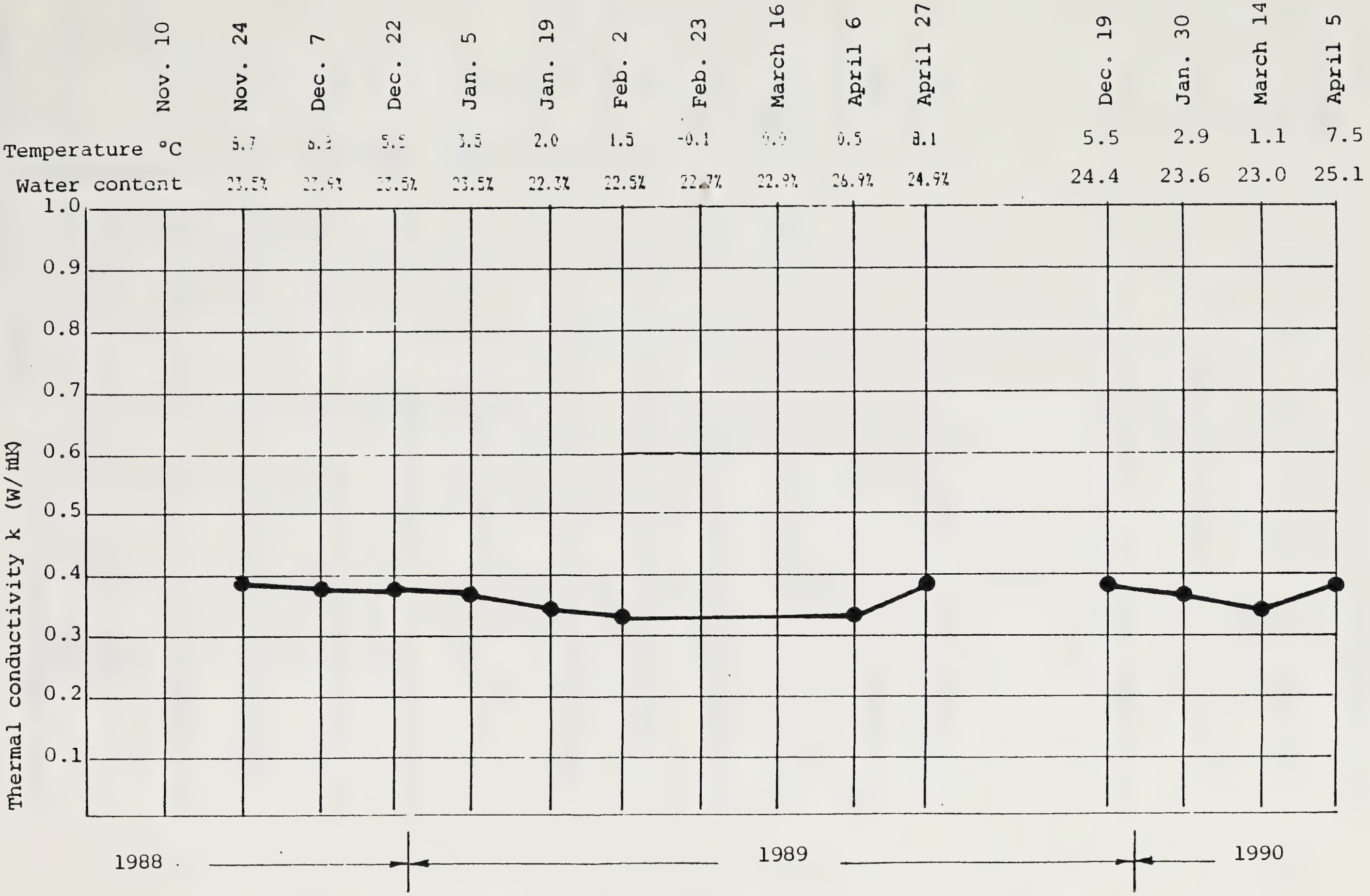


Fig. 4.5 Thermal conductivity of GRANULITE vs. time in Test 6

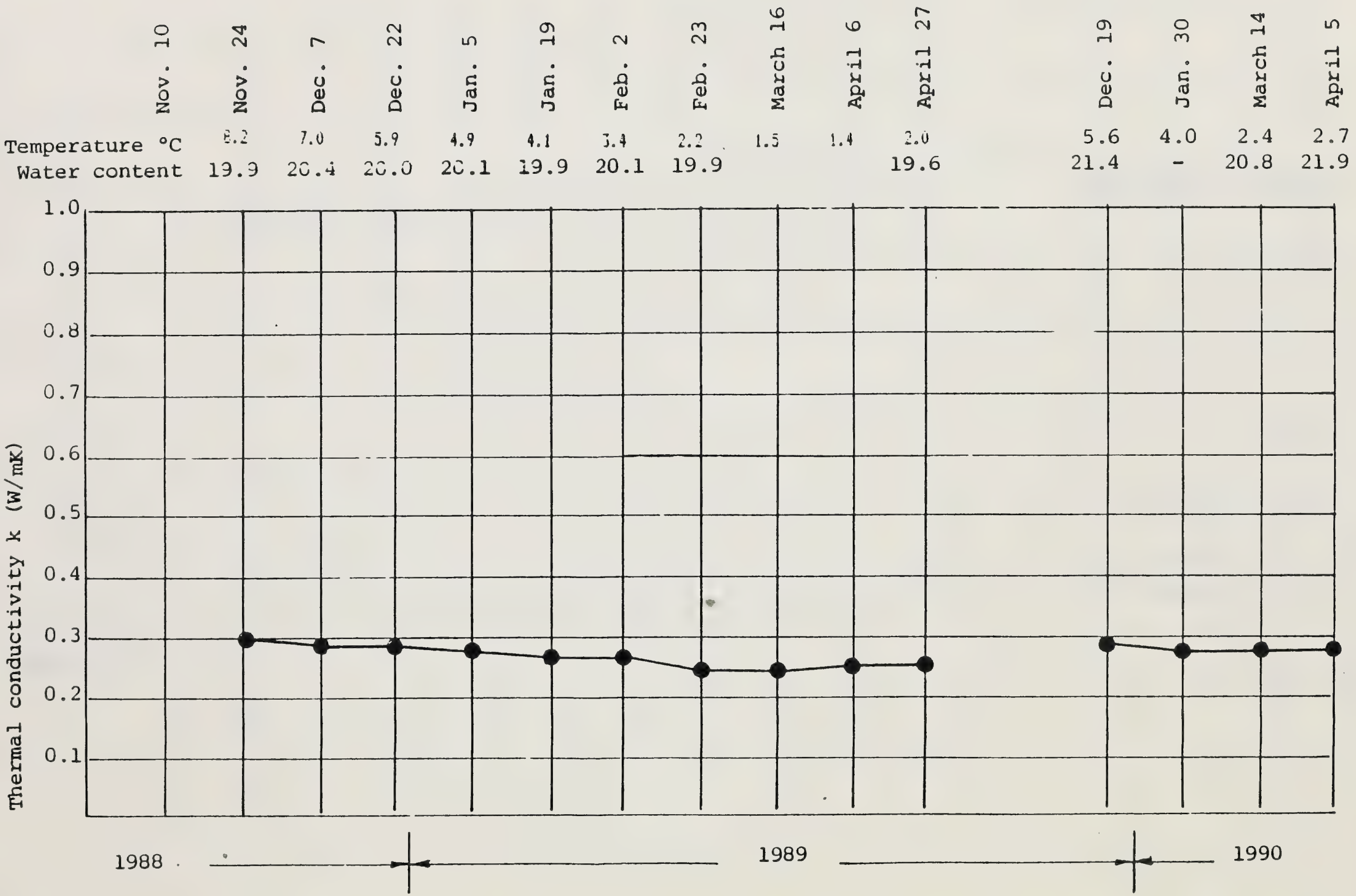


Fig. 4.6 Thermal conductivity of GRANULITE vs. time in Test 8 (probe 8-1)

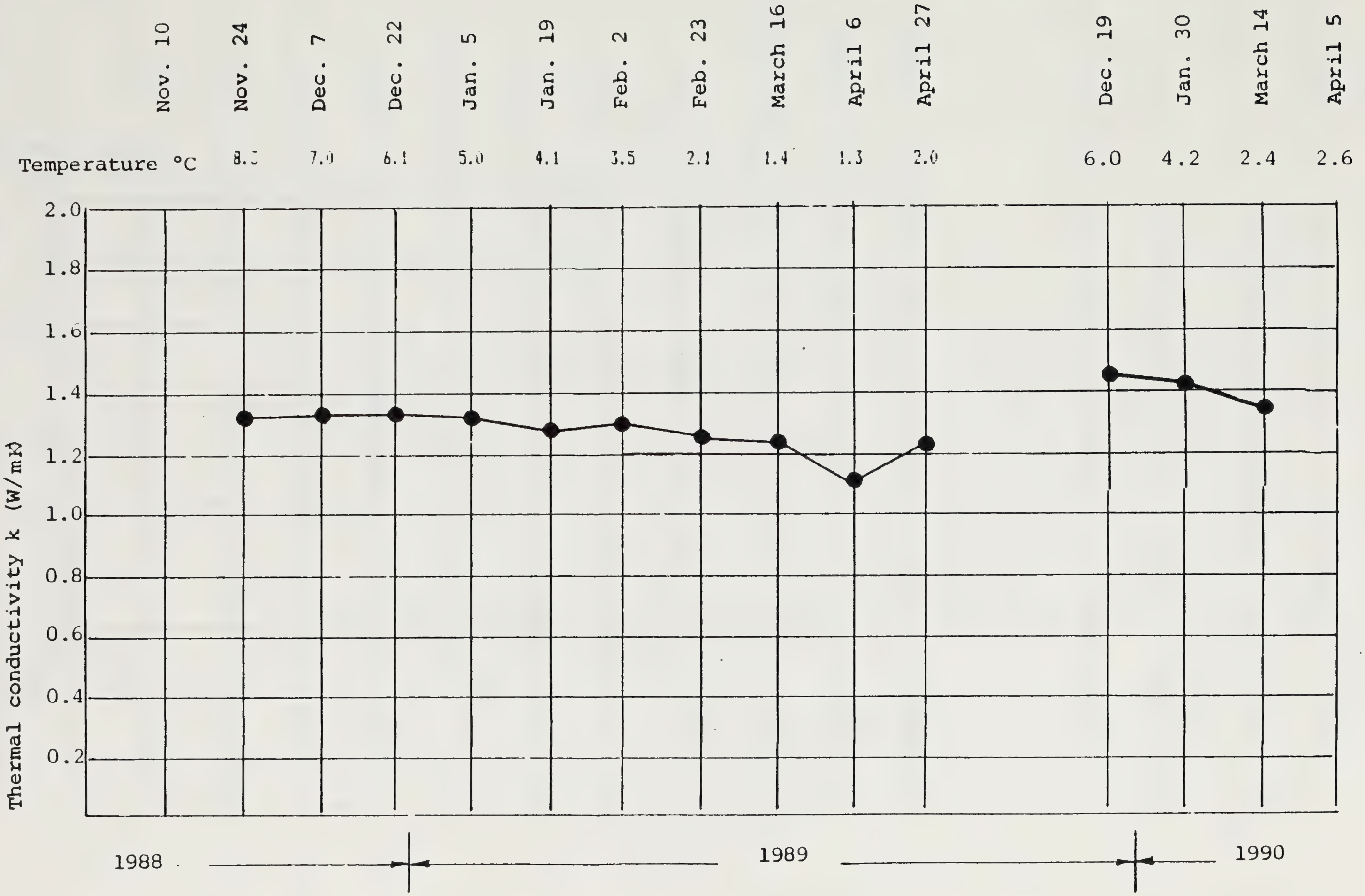


Fig. 4.7 Thermal conductivity of soil vs. time in Test 8 (probe 8.2)

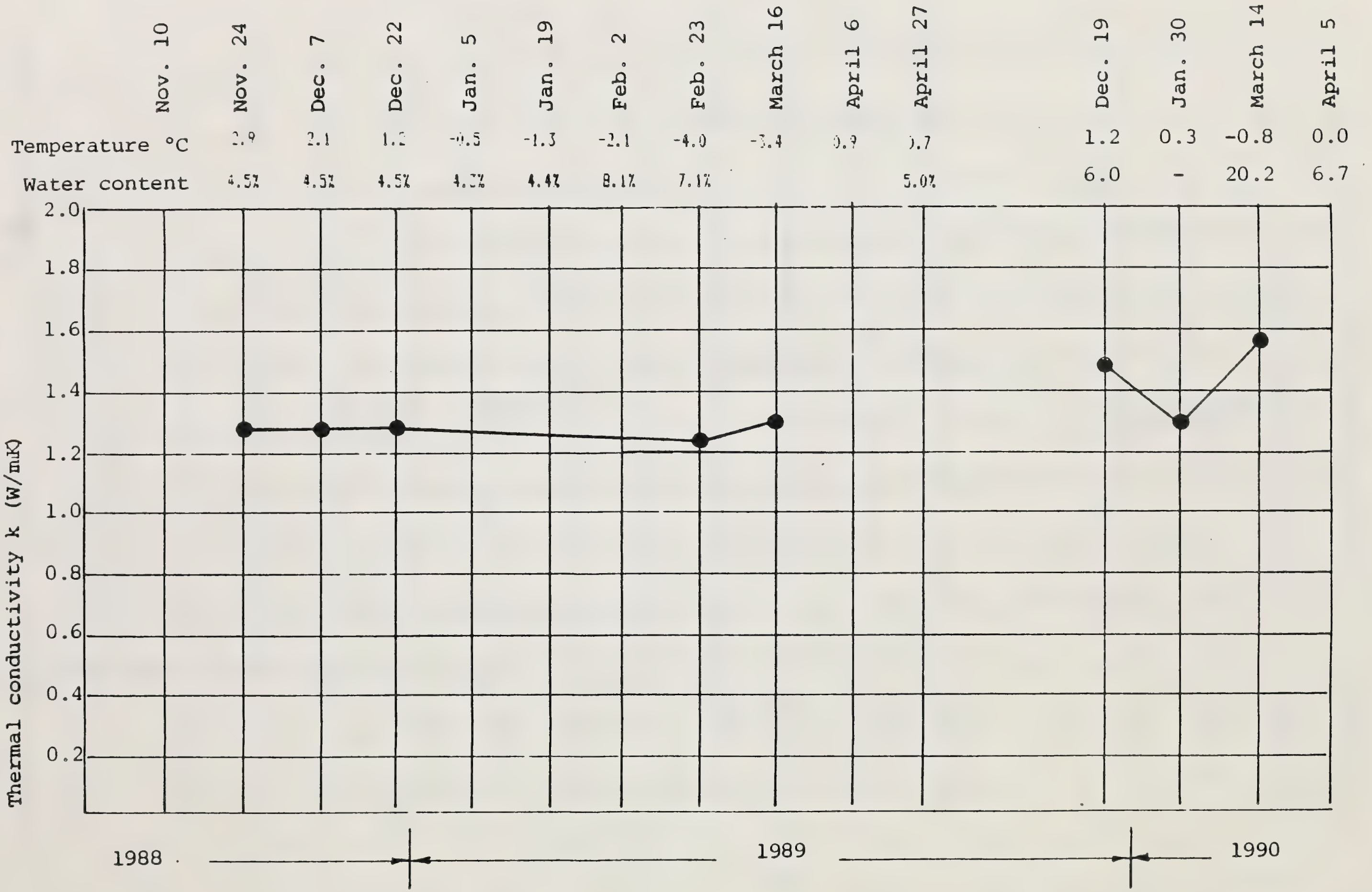


Fig. 4.8 Thermal conductivity of soil vs. time in Test 8 (probe 8-3)

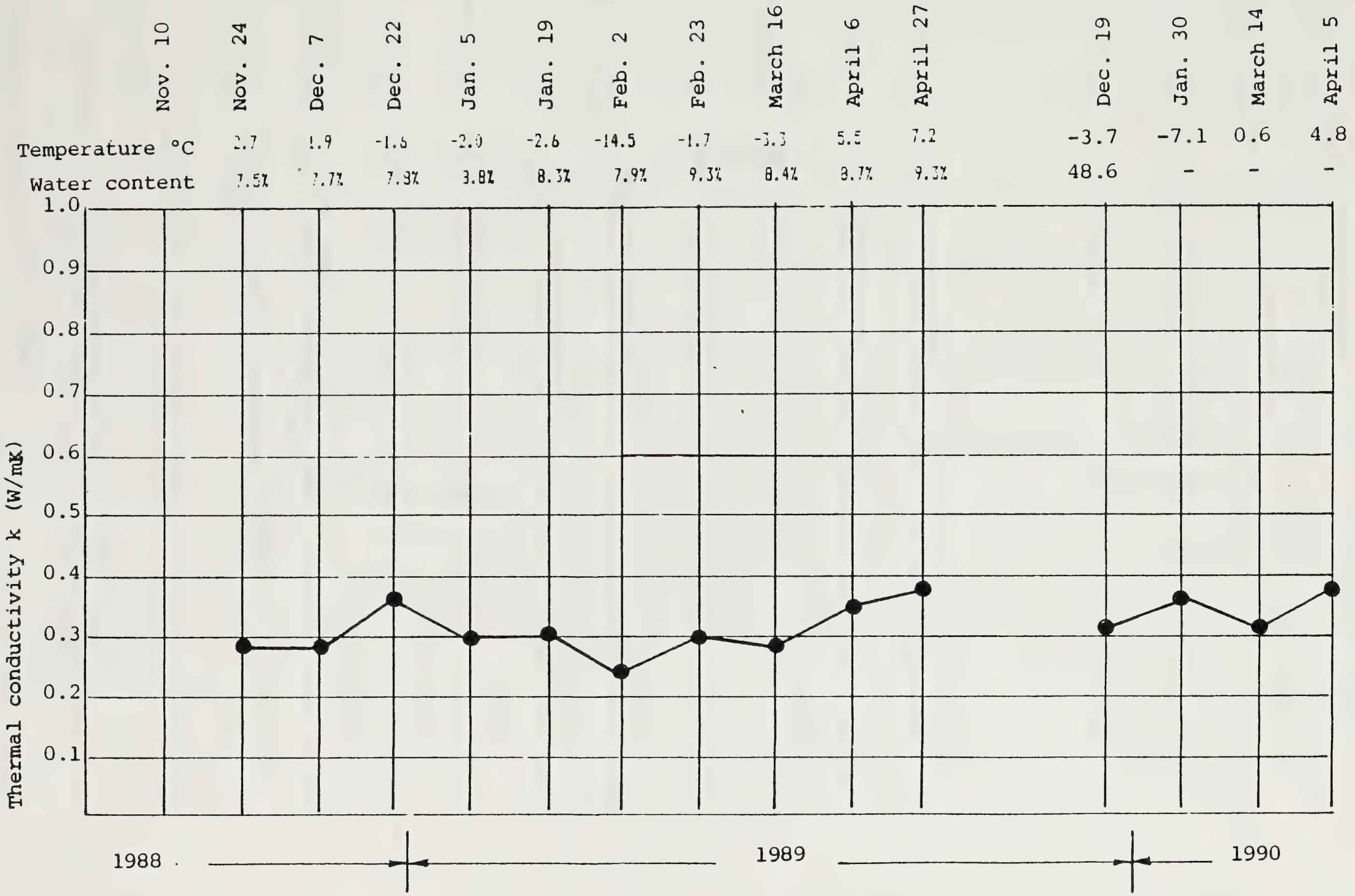


Fig. 4.9 Thermal conductivity of GRANULITE vs. time in Test 9 (Road section)

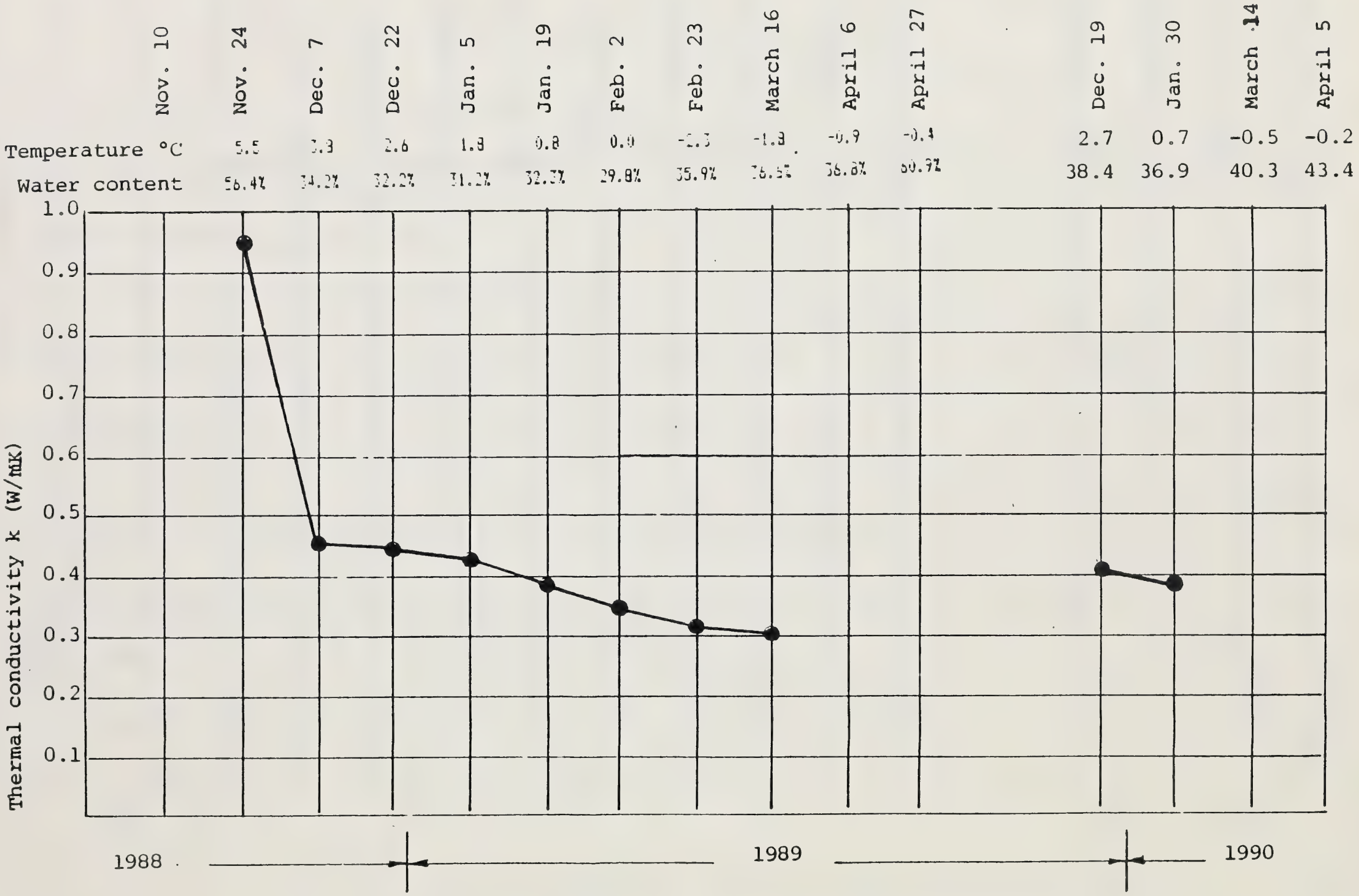


Fig. 4.10 Thermal conductivity of GRANULITE vs. time for Test 11

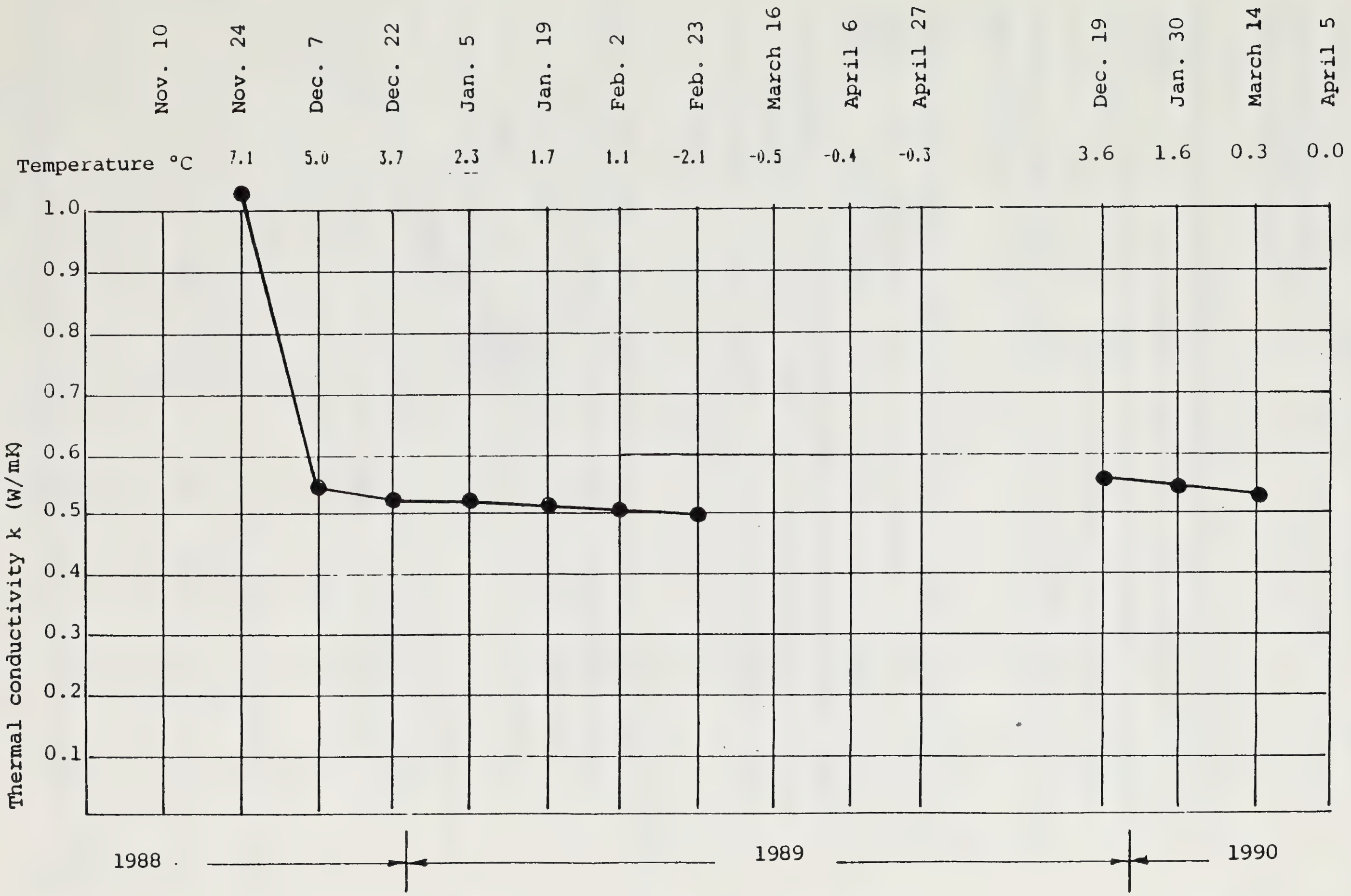


Fig. 4.11 Thermal conductivity vs. time for Test 12 (Insulating Fillcrete)

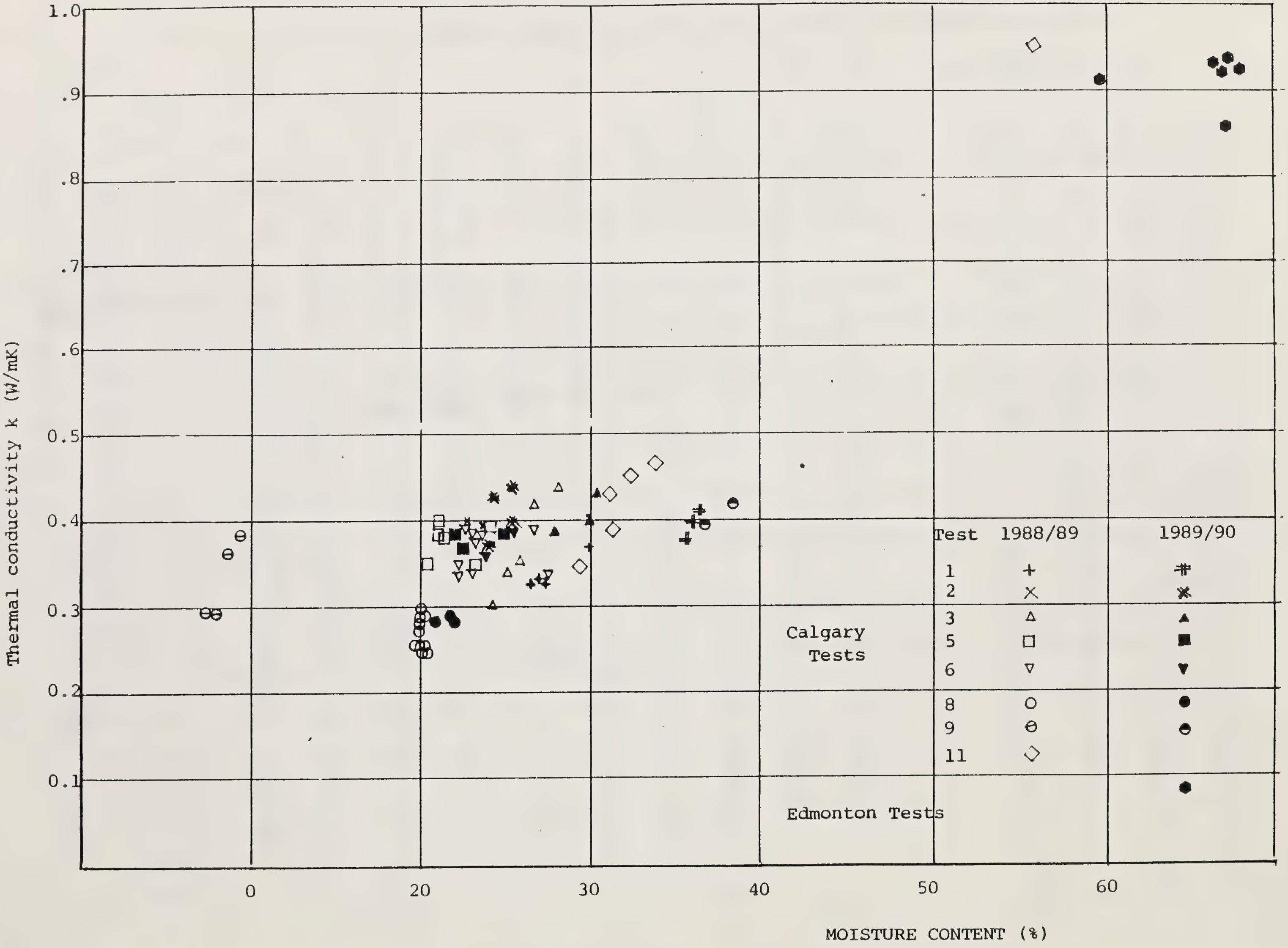


Fig. 4.12 Summary of thawed thermal conductivity data

4.3 Evaluation

As described previously, a design value of $k=0.3W/m^{O}C$ at a moisture content of 17% by weight was proposed for the Granulite in the original trench design (Figure 2.1).

There has been no significant change in the moisture condition of the Granulite in the test trenches or in the k-values of the Granulite from the original values measured in the winter of 1988/89. Some slight increase in several k-values was noted in 1989/90, however these changes appear to be the result of modest changes in moisture content at the same locations.

Moisture and thermal conductivity changes are self-compensating to a degree, when considering frost protection capability. The reason is an increase in moisture which leads to a reduction in the insulating value of Granulite. This increases the latent heat of the material, which slows down the rate of frost penetration. This results from the release of the latent heat of the moisture as the zero degree isotherm advances and the moisture turns to ice at the same temperature.

Under the observed low range of moisture content at the Manchester site, freezing of the Granulite did not lead to any significant increase in the thermal conductivity. On the other hand, at the Forest Lawn site with its higher moisture content, the Granulite did not freeze at all, likely due to the high latent heat of the water.

In summary, the design properties of both frozen and unfrozen Granulite, assumed in the original design of the pipe trench and described in Section 2.4 were duplicated by this study.

4.4 Comparison with Edmonton Data

It must be noted that the Edmonton test installation is located in a very swampy area with a high water table. Therefore, a direct comparison between Calgary and Edmonton results cannot be made. Further, the Calgary and Edmonton Granulite products are produced from different raw materials and have somewhat different physical properties. Nevertheless, as a matter of qualitative evaluation, some of the relevant Edmonton data related to high moisture content are added to Figure 4.12. These data points confirm that there is a significant increase in the k-value for saturated conditions.

5.0 CONCLUSIONS

5.1 Trench Design

The opportunity to have a "second look" at the underground conditions in the original Calgary test trenches has provided important information regarding the behaviour of Calgary Granulite. Specifically, the results of this test series permit the following comparisons and conclusions.

(a) Both the moisture content and the thermal conductivity values measured during this test program nearly equal to the values measured during the original test series.

(b) At low moisture contents, the values of thermal conductivity of Granulite in thawed and frozen conditions nearly the same.

(c) The values for thermal conductivity (k) and moisture content (MC), increased in 1989/90, and were modestly higher than the design values of k=0.3 and MC=17%, selected for the 1988/89 trench design shown in Figure 2.1. The above design values were selected to yield a conservative design.

It was, therefore, concluded that no change in the original design values was warranted and the original trench design is still valid for Calgary conditions.

(d) It may be expected that longer term burial of Granulite under stable moisture conditions in the trench and surrounding native soils will result in stable, equilibrium conditions of moisture in the Granulite, with steady thermal characteristics.

It is important to note that the trench design given in Figure 2.1 is valid only for Calgary conditions.

For other jurisdictions, the following factors must be considered in developing a specific trench design utilizing Granulite as pipe insulation:

1. Native soil conditions.
2. Backfill materials.
3. Moisture conditions of soil and backfill.
4. The design Freezing Index and anticipated snow cover.

5.2 Other Considerations

The cost of watermain installation or replacement is largely dependent upon the experience, materials handling methods and unit rates for equipment and labour of a particular contractor. Economic conditions also influence bid prices.

At the time of writing, no contractors in the Calgary area have used Granulite on a major project other than on a "cost-plus" basis, at the request of the City of Calgary Waterworks officials. There is generally no cost history available on the use of Granulite in a shallow, narrow trench versus more traditional construction techniques.

It was for this reason that the City of Calgary Waterworks Department elected to undertake extensive cost studies of actual installations in the 1990 construction season. A formal report on the results of these studies is not in the public domain. However, the Waterworks Department indicated that savings of 10% to 15% were realized using the Granulite and shallow buried pipe construction method over traditional deep pipe methods. In addition, the City of Calgary reported faster construction, cleaner project sites, improved labour attitudes, improved public relations in work areas and more rapid pavement repairs.

On the basis of this favourable experience, the City of Calgary Waterworks Department has included the shallow, Granulite insulated pipe construction method as an approved alternate for outside contractors bidding on City projects, in their 1991 Standard Specifications for Waterworks Construction. It is, therefore, anticipated that the City of Calgary will use this new technique extensively in an enlarged program plan in 1991. The increased construction program is attributed in part to the cost savings achieved with the new technology.

6.0 REFERENCES

1. "Thermal Conductivities of Expanded Shale and Clay Lightweight Aggregates"
   L. E. Goodrich and T. L. White, September 1987

2. "Report on Laboratory Testing of Lightweight Aggregate"
   EBA Engineering Consultants Ltd. - Report No. 0304-32927-002
   Prepared for WPL Engineering Ltd., June 1987

3. "Frost Protection of Underground Water Pipes"
   Dr. W. H. Dilger, University of Calgary and
   Dr. L. E. Goodrich, National Research Council Canada, July 1989.

APPENDIX "A"

DESCRIPTION OF TESTS

A CONDENSATION OF SECTION 2.0
OF THE ORIGINAL STUDY

"FROST PROTECTION OF UNDERGROUND WATER PIPES"

APPENDIX A

DESCRIPTION OF TESTS

Manchester Site - FIGURE A.1

Tests 1 to 4 are performed in trenches which are 1.675m deep, 1.80m wide and 5.00m long.

Test 1 - Figure A.2

Test 1 features a 375 mm thick layer of pea gravel at the bottom of the excavation. This layer would, in an actual situation, contain the waterpipe. The 300 mm thick layer of Granulite above the pea gravel is fully enclosed by a layer of geotextile. The geotextile fabric is intended to prevent fines from filling the voids between the Granulite particles which would reduce the insulating effect of Granulite.

The pit was backfilled with common fill, previously excavated from the pit and compacted in layers. After the installations were completed and all pits backfilled, the whole strip was asphalted in one operation.

Test 2 - Figure A.3

The difference between Test 2 and Test 1 is that the Granulite is enclosed with a 6 mil polyethylene sheet.

Test 3 - Figure A.4

This test differs from Test 1 in that the backfill material is imported clay.

Test 4 - Figure A.5

While the dimensions of the pit are the same as those of the first three tests, the layer of pea gravel is covered by a 76 mm layer of Styrofoam HI-60. The pit was backfilled with common fill.

Test 5 - Figure A.6

The depth as well as the width of the excavation is 1.80 m for Tests 5 and 6, and the length is 5.00 m. A 300 mm thick layer of Granulite is placed on the bottom of the pit and well compacted. The watermain would be placed in this lower layer in a real situation. The compacted Granulite is overlain by another (non-compacted) layer of Granulite with a nominal thickness of 400 mm in the middle and a reduced thickness at the edges. The Granulite is covered with geotextile fabric. The backfill material is common fill which is well compacted.

Test 6 - Figure A.7

This test is similar to Test 5 except that the Granulite is not covered with a geotextile fabric.

Test 7 - Figure A.8

As shown in Figure A.1 Tests 7 and 8 are in a common trench along an existing 203 mm diameter watermain. The trench is 1.50 wide, about 10.0 m long and for Test 7 the excavation is 2.35 m deep. After installation of the thermocouples the excavated material was backfilled and compacted.

Test 8 - Figure A.9

In this test, soil was excavated to a depth of 200 mm below the bottom of the watermain resulting in a trench depth of 2.50 m. Granulite was then placed in the mid-depth of the pipe and compacted. A layer of Granulite up to 400 mm thick was placed next before the trench was backfilled with well compacted common fill.

Test 9 - Figure A.10

This test represents a road section with a 300 mm thick layer of Granulite placed below a 100 mm layer of crushed gravel and a 200 mm layer of asphalt. In the centre of the 5.00 m by 5.00 m test section, a 2.60 m deep, 0.60 m diameter hole was drilled to accommodate temperature sensors.

Test 10 - Figure A.11

The 3.00 m deep, 0.60 m diameter augured hole served to place temperature sensors to establish the normal temperature profile without insulation.

The excavation at the Manchester Site started on October 3, 1988 and the pavement covering the test sections was placed on October 14.

The Forest Lawn Site - Figure A.12

At the Forest Lawn Site a rather wet, fine grained, clay material was encountered. The high ground water level is due to the proximity of a small pond adjacent to the site. Two test pits were excavated near a small heated sanitation shack (see Figure A.12). Both pits were 1.75 m deep, 1.80 m wide and 5.00 m long.

Test 11 - Figure A.13

As shown in the figure, a 500 mm thick layer of Granulite was enclosed by a sheet of polyethylene. Since the excavated material was too wet, the backfill material was imported, dried (re-cycled) clay which was compacted in layers.

Test 12 - Figure A.14

In this test the whole pit was filled with so-called Insulating Fillcrete - a very low strength, no-fines, lightweight concrete - after installation of the temperature sensors. The Forest Lawn installations were performed October 12 to 14, 1988.

The fieldwork was coordinated by Mr. Mikhail Pildysh, P. Eng., of Pildysh Consulting Services Inc., in cooperation of Mr. Philip Stan, C.E.T. of the City of Calgary.

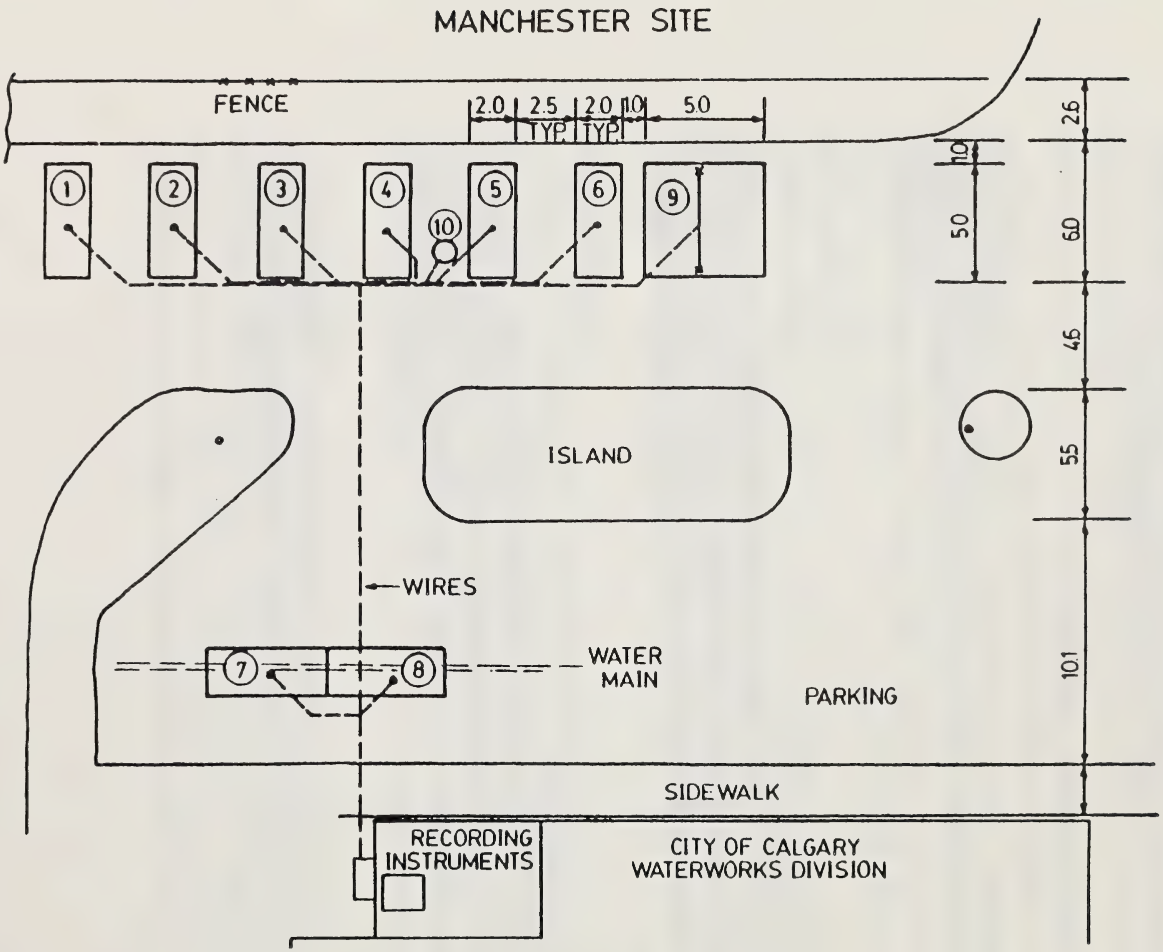


Figure A.1 Layout of Tests at Manchester Site

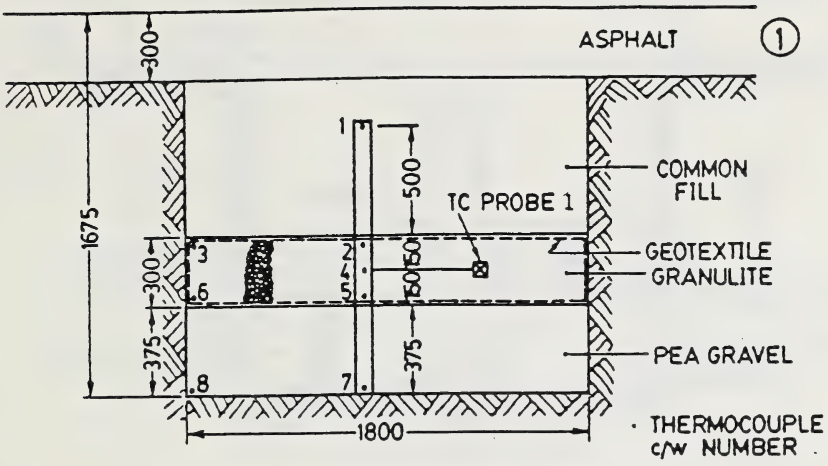


Figure A.2 Section Through Test 1

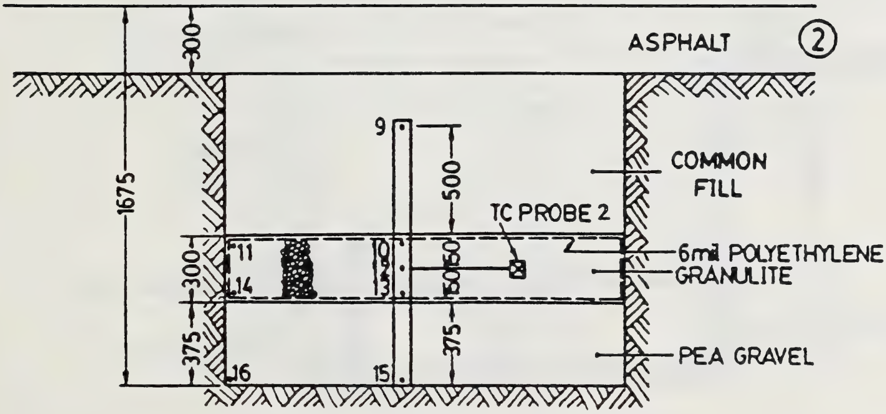


Figure A.3 Section Through Test 2

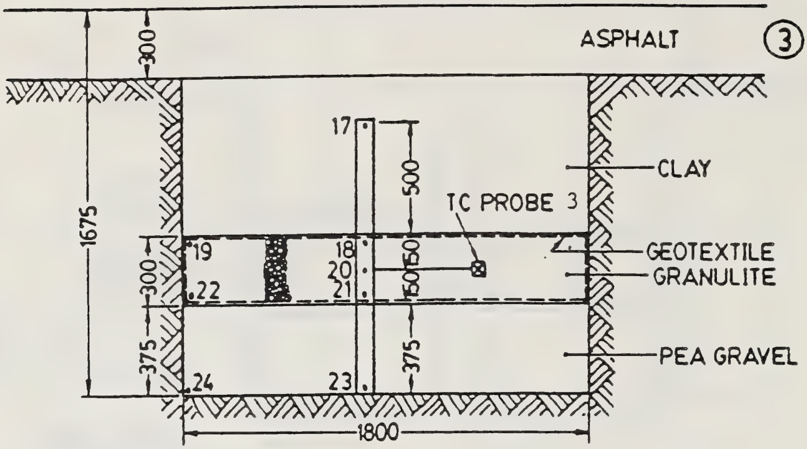


Figure A.4 Section Through Test 3

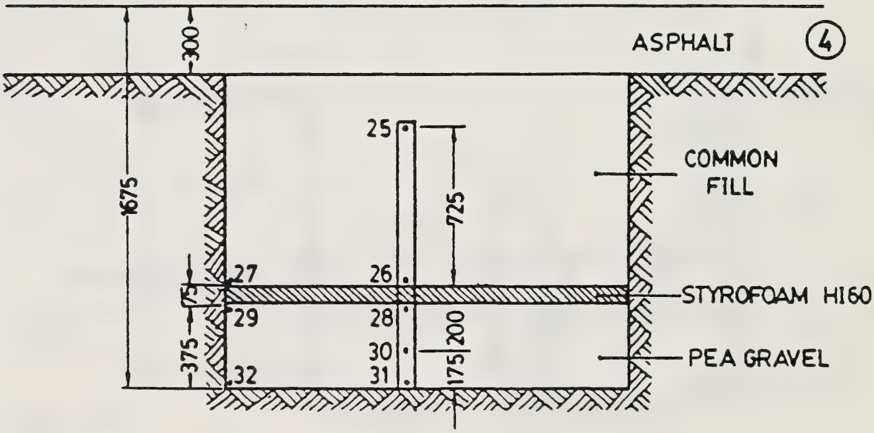


Figure A.5 Section Through Test 4

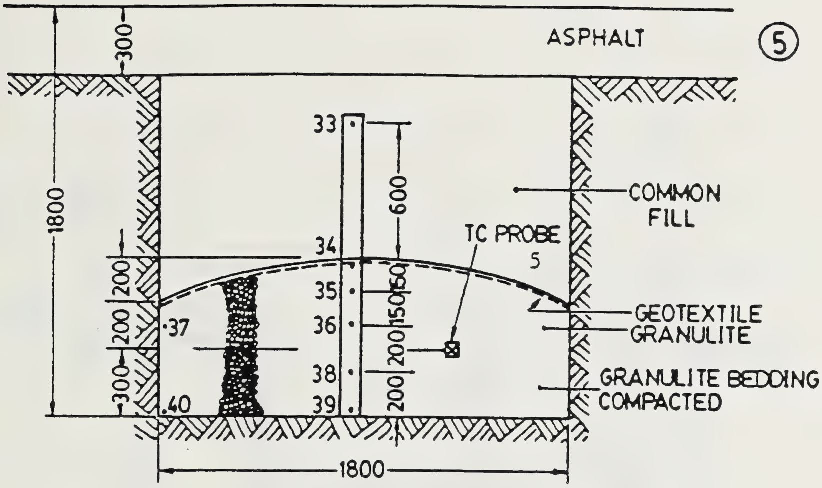


Figure A.6 Section Through Test 5

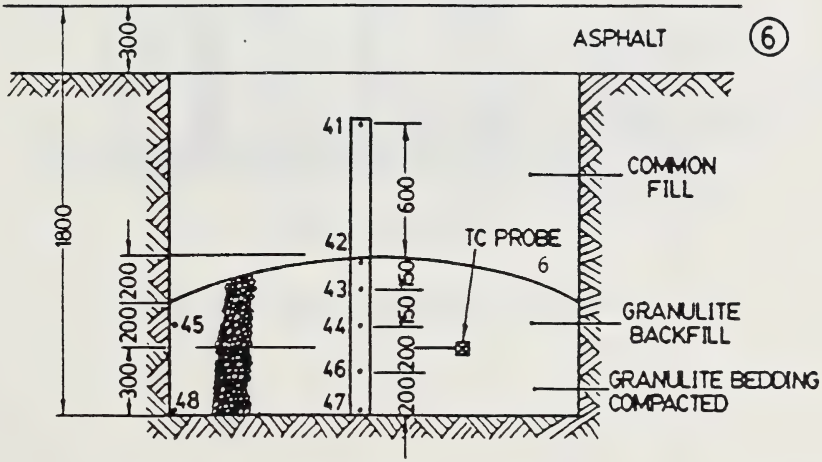


Figure A.7 Section Through Test 6

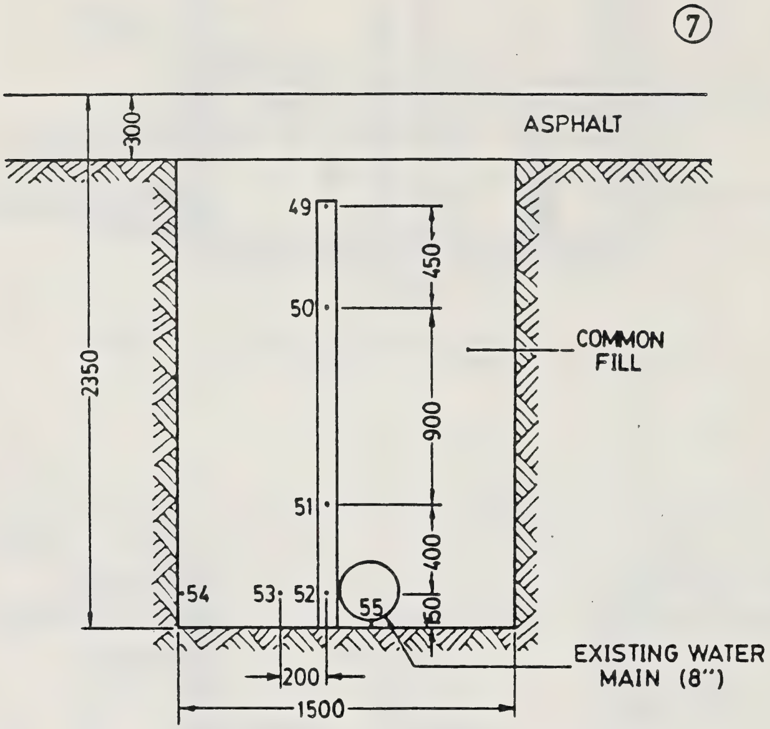


Figure A.8 Section Through Test 7

⑧

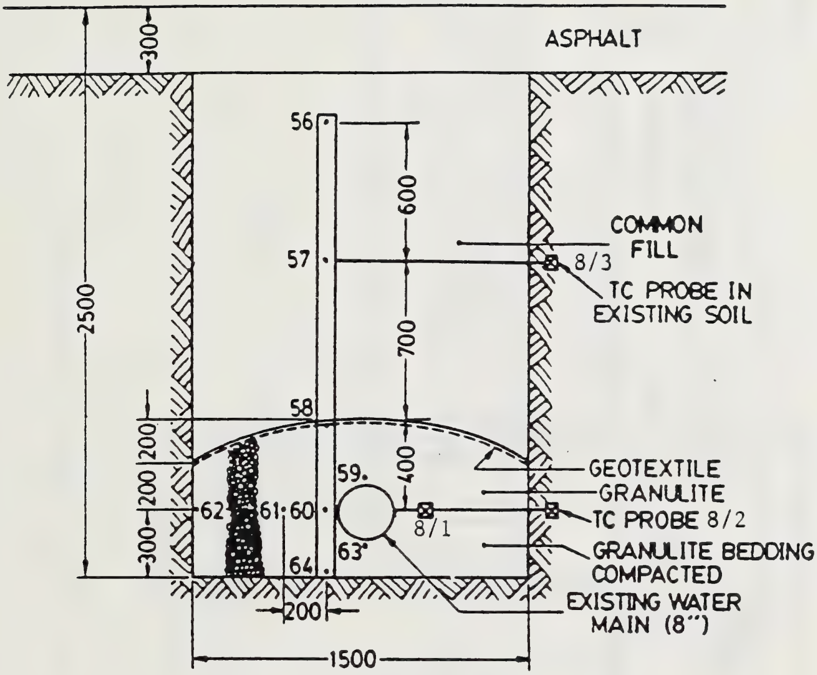


Figure A.9 Section Through Test 8

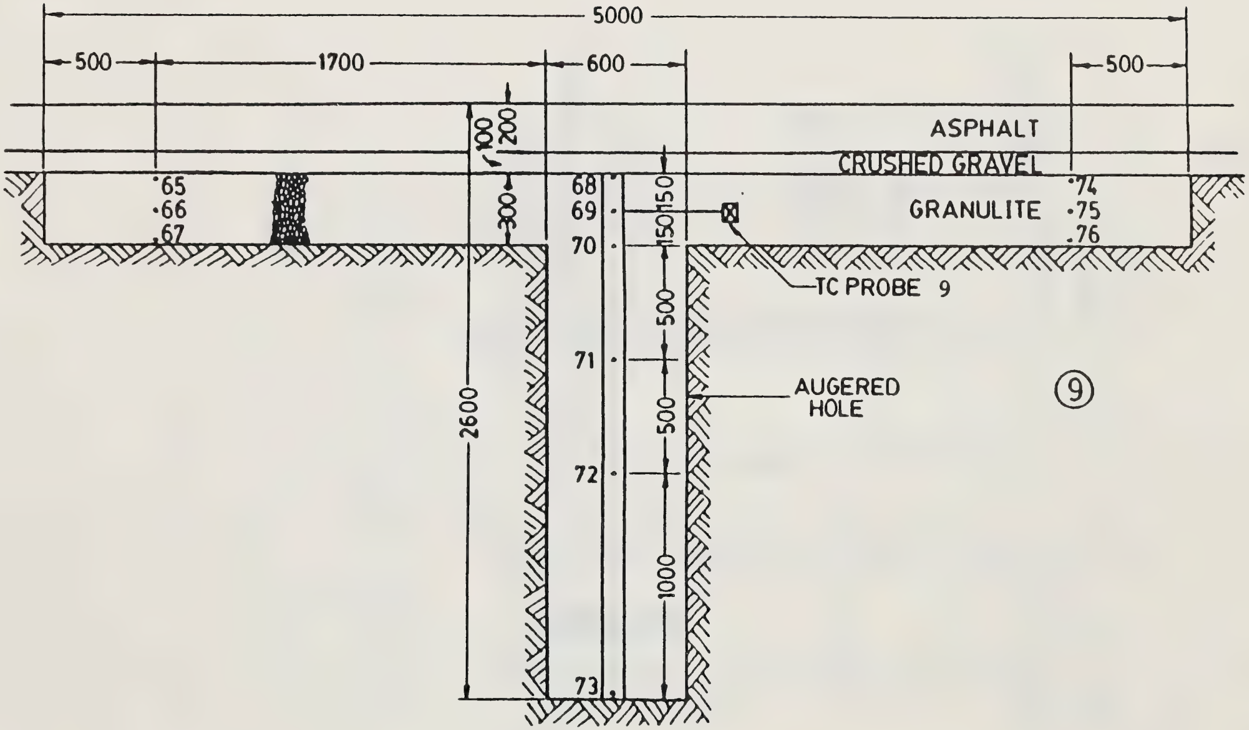


Figure A.10 Section Through Test 9

⑩

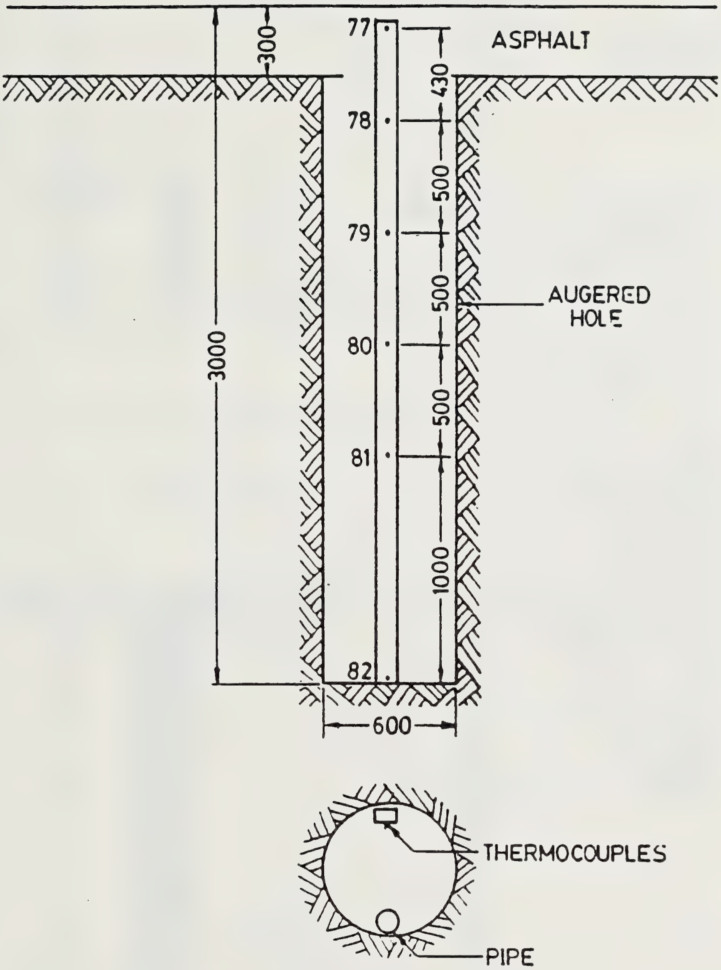


Figure A.11 Section Through Test 10

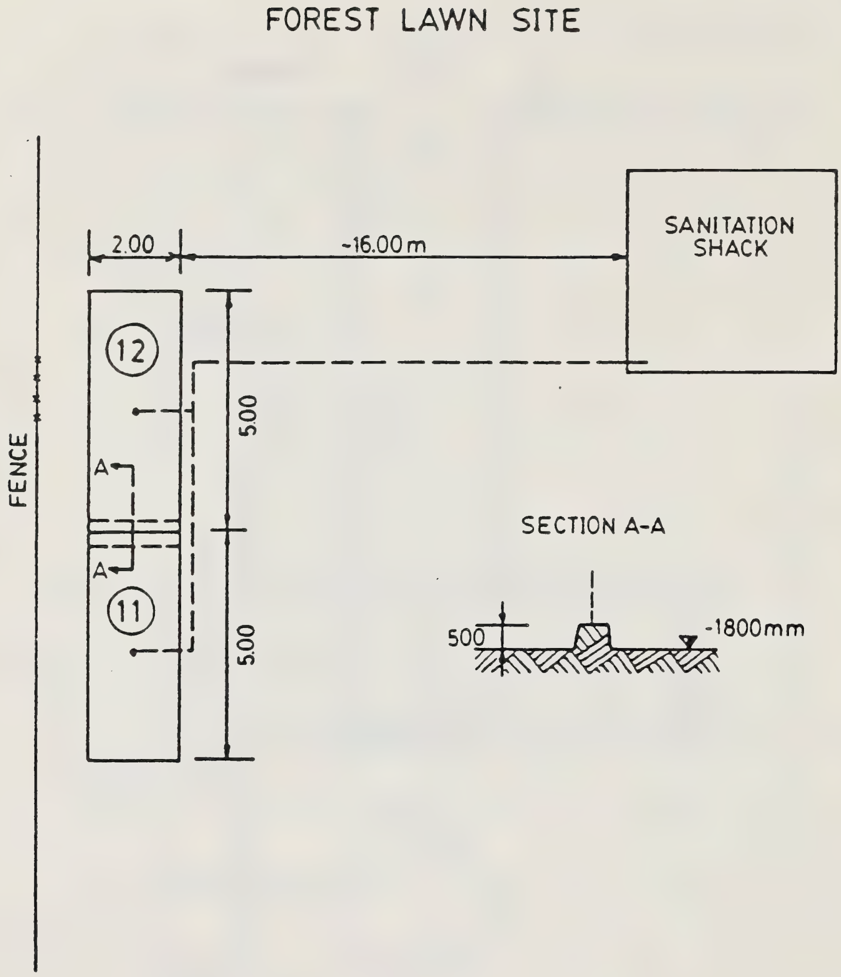


Figure A.12 Layout of Test at Forest Lawn Site

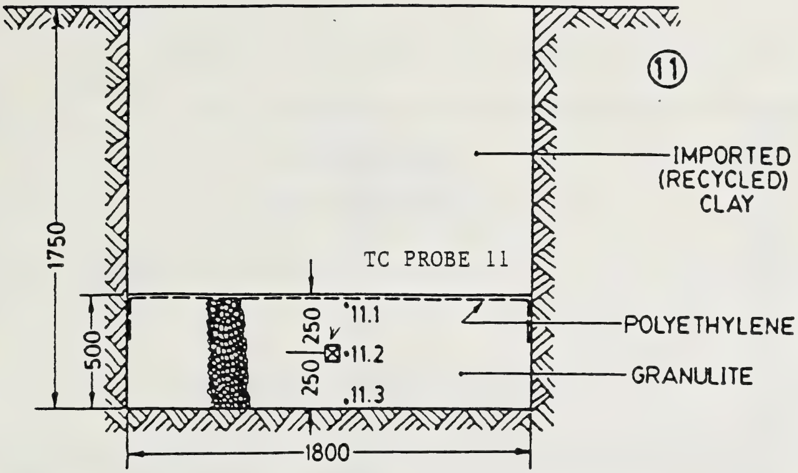


Figure A.13 Section Through Test 11

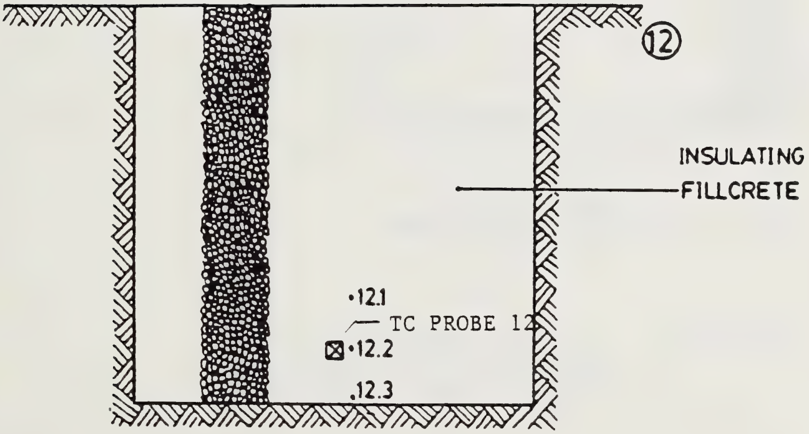


Figure A.14 Section Through Test 12

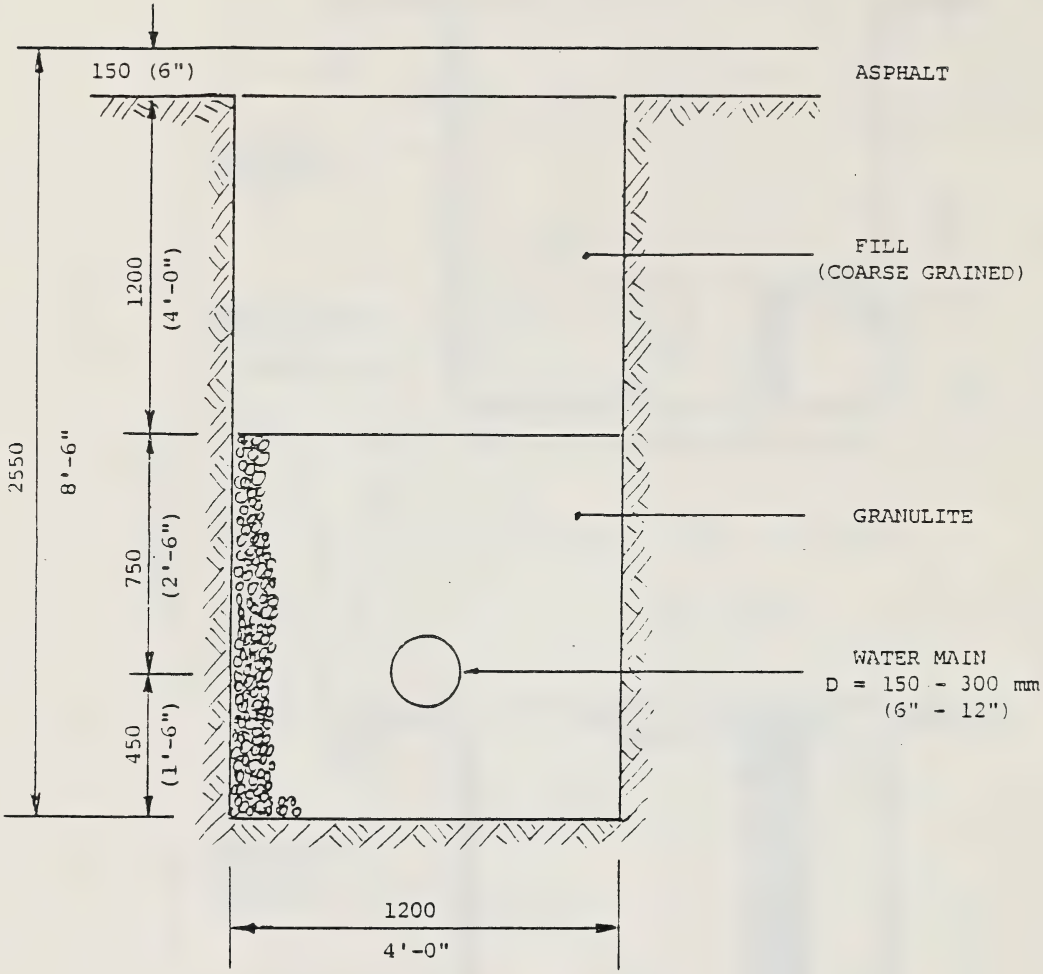


Figure A.15 Proposed Configuration for Insulation of Water Main for CALGARY Climatic Conditions.

APPENDIX "B"

MEASUREMENTS

A CONDENSATION OF SECTION 3.0
OF THE ORIGINAL STUDY

"FROST PROTECTION OF UNDERGROUND WATER PIPES"

APPENDIX B

Excerpt from Original Study
"Frost Protection of Underground Waterpipes"

MEASUREMENTS:

Temperature

The purpose of these tests was to establish the effectiveness of Granulite as an insulating material. This was achieved by measuring the temperature profiles through the test sections by means of thermocouples and by measuring the thermal conductivity of the material in-situ. At the Manchester Site temperature measurements were taken, in general, once a day during the six month test period. During the period of extremely cold weather, more frequent readings were taken.

The locations of the temperature sensors (thermocouples) are indicated on the cross-sections through the test pits (Figures A.2 to A.11, A.13 and A.14, together with the numbering of these sensors. For convenience, the numbering is also summarized in Table B.1.

TABLE B.1

Thermocouple and Conductivity Probe Information

TEST NO.	THERMOCOUPLE NUMBER	THERMAL CONDUCTIVITY PROBE NUMBER	LENGTH of WIRES (m)	MOISTURE CONTENT MEASUREMENT
1	1-8	1	43.5	Yes
2	9-16	2	39.0	Yes
3	17-24	3	34.5	Yes
4	25-32	-	30.5	No
5	33-40	5	32.0	Yes
6	41-48	6	37.0	Yes
7	49-55	-	23.0	No
8	56-64	8-1; 8-2, 8-3	18.0	Yes
9	65-76	9	42.0	Yes
10	77-82	-	30.5	Yes
11	11-1, 11-2, 11-3	11	24.0	Yes
12	12-1, 12-2, 12-3	12	29.0	No

The thermocouples were manufactured with copper-constantan wire, notation NN-24-T, a product of Thermo Electric, Brampton, Ontario. The two wires were connected by a silver tip (so-called QUICKTIP) which was squeezed on to the wires with a special tool under high pressure. The thermocouple end was embedded in silicone inside a 6 mm O.D. copper tube. To maintain their position during installation in the field, the thermocouples arranged along a vertical line (i.e. numbers 1, 2, 4, 5, and 7 in test 1), were fastened to wooden studs 38 x 89 mm (2" x 4") as shown in Figure B.1. At the desired elevations 6 mm diameter holes were drilled to accommodate the 6 mm copper tube in a press fit. In addition to drilling the holes, 5 mm wide and 10 mm deep transverse and longitudinal grooves were cut into the studs to accommodate the wires. Insulation tape was wrapped around the studs holding the wires inside the grooves to protect them from mechanical damage during installation, backfilling and compaction. Because of these precautions all of the thermocouples worked perfectly during the duration of the tests.

The thermocouples located 750 mm away from the studs had a 750 mm long wire projecting from the stud with 50 mm long, 6 mm O.D. copper tubing at the end in which the thermocouple was embedded (see Figure B.2).

To lead the wires to the data logger which was located in a heated office of the Waterworks Division, considerable wire lengths were required. These lengths are recorded in Table B.1. The thermocouples were manufactured and assembled in the Electronics Laboratory of the Department of Civil Engineering at The University of Calgary. The sequence of manufacturing involved the following steps:

- cutting, numbering and bundling of wires for each test,
- preparation of studs complete with copper tubes,
- insertion of wires into copper tubes and grooves,
- cutting of wires to correct final length,
- application of silver Quicktip,
- protection of tip with acrylic coating,
- embedding tips in silicone inside the copper tube,
- attachment of thermoprobe wire to stud,
- pulling of wires through 28 mm pvc tube,
- fastening of tube to top of stud.

The vinyl ducts were approximately 3 m shorter than the wire length. This conduit served as protection in the soil from the test pit to the recording equipment which was located inside the offices of the Waterworks Division of the City of Calgary at Manchester (see Figure A.1) or to the sanitation shack at Forest Lawn (see Figure A.12). These conduits also contained the wires for the thermal conductivity probes.

The completed stud with thermocouples and thermoprobe for Test 1 is shown in Figure B.3. To hold the studs in the desired position in the test pits, small 25 x 25 x 4 mm steel angles were pounded into the soil approximately 400 mm deep, the studs being fastened to it by means of wood screws (see Figure B.1).

A total of 81 thermocouples were installed at the Manchester site. Two additional thermocouples were used to record the outside air temperature, and on February 4, 1989 one more thermocouple was installed to record the room temperature near the data acquisition system.

At the Manchester site the temperature was monitored automatically with a 100 channel FLUKE data acquisition system consisting of a Fluke Model 2030, a printer, a Fluke Model 2190 digital thermometer, one Fluke Model 2300 Scanner and two Model 2301 Scanner extenders.

At the Forest Lawn site three thermocouples were installed in each test pit and another to record the ambient temperature. The temperatures were recorded manually with a DORIC digital thermometer. From the end of October 1988, to the end of January 1989, the temperature was recorded at two week intervals. After January 23, 1989, the readings were taken four times a week by a City of Calgary employee working at the site.

Thermal Conductivity

The thermal conductivity was measured by means of thermal conductivity probes developed by the National Research Council of Canada and manufactured by GEOTHERM of Ottawa. The probes consist of a 500 mm long by 14 mm diameter brass tube and use a bifilar wound constantan heater coil wound onto a thin-walled brass inner tube and with a temperature measuring thermistor mounted inside the cylindrical heater coil at mid-length. An acrylic plastic casting resin is used to form the head, completely encapsulating soldered connections to the lead wires. The probe barrel is filled with urethane foam. Details of the probe construction are shown in Figure B.4. Operation is simple in principle, and entails calculation of the thermal conductivity from the slope of the temperature response curve when the probe is heated at a fixed rate.

The thermistors chosen as temperature sensors are capable of detecting temperature changes of a few millikelvins. This makes it possible to operate the probes with very low power levels thus reducing troublesome thermal gradients near the probe and diminishing the associated deleterious effect of moisture transport. The field measurements were made using a portable battery-operated field instrumentation package, consisting of a digital multimeter, a printer capable of simple graphics, a manually operated (integrated-circuit-based) regulated constant voltage source with switch selectable output voltage levels operating from sealed lead-acid batteries and hand held programmable calculator with integral digital clock. The thermal conductivity probes were installed horizontally at mid depth of the Granulite layer (see Figures A.2 to A.11 and A.13 and A.14. No probes were installed in Tests 4, 7 and 10 which did not contain any Granulite. Test 8 contained three probes - one in the Granulite and two at different levels in the surrounding soil (Figure A.9). The apparatus worked well in general, however, as expected around the freezing point, the measurements were falsified by latent heat effects associated with the moist materials.

Moisture Content

The sub-surface moisture content of the Granulite and of the soil was measured by a Model 503 DR Hydroprobe, Neutron Depth Moisture Gauge. This instrument is manufactured by the CPN Corporation in Martinez, California, U.S.A. It measures the in-situ moisture content in soil and other materials by use of a probe containing a source of high energy neutrons and a slow (thermal) neutron detector. The probe is lowered into a cased hole 40mm (1.5 inches) in diameter. Hydrogen present in the soil moisture slows the neutrons down for detection. The moisture data is displayed directly in percent by volume on an above ground electronic assembly which is integral to the source shield assembly. The gauge is supplied with a 3.66 m (12 feet) long cable and five adjustable cable stops.

Upon retraction of the probe into the shield, the probe locks automatically in place for transportation. Because of the radioactive material contained in the probe, a special University of Calgary vehicle had to be used and the technicians had to be specially trained in the use of this probe and the vehicle. The Hydroprobe comes with a standard calibration in sand. This calibration was used for the backfill material. However, for the Granulite special calibrations were necessary. For the calibrations two barrels of Granulite were used. The Granulite of Barrel 1 was air dried by spreading the material on the laboratory floor to dry overnight and filled back into the barrel. Samples of exactly 0.25 cubic foot were taken from the mid-depth of the barrel and water content determined by drying overnight in an oven at 105°C. The water content by weight was 0.3%. This information was fed into the electronic assembly and was denoted "CALIB 13". The same procedure was repeated with the Granulite in Barrel 2 which was soaked overnight and drained before establishing its moisture content at 13.5% by volume corresponding to 19.3% by weight. The resulting calibration was called "CALIB 14". Subsequent measurements for CALIB 13 resulted in the following moisture contents:

in "dry" Barrel 1 - 0.2% by volume
- 0.3% by weight
in "wet" Barrel 2 - 13.5% by volume
- 19.3% by weight

Using CALIB 14, the following readings were registered:

in "wet" Barrel 2 - 13.6% by volume
- 19.4% by weight

Additional measurements in water yielded 98.5% and 100.4% by volume for CALIB 13 and CALIB 14, respectively for the theoretical value of 100%. These measurements further confirmed the calibrations.

Both calibrations were used for the field measurements and they resulted in almost identical results.

The factory calibration "CALIB 1" was used for the moisture measurements in the natural soil.

For the moisture content measurements a 38 mm I.D. aluminum pipe was installed in all the test pits with the exceptions of Test 4 (Styrofoam) and Test 12 (Insulating Fillcrete). The pipe was closed at the bottom with a welded plate and a rubber bung was used to prevent moisture penetration at the top. To protect the pipe from traffic, a small top box was used. The assembly is shown schematically in Figure B.5.

Some of the pipes were bent considerably during paving of the road, but all of them could be used for monitoring of the moisture content.

Once or twice ice formed inside the top of some of the pipes during the tests and moisture content could not be measured.

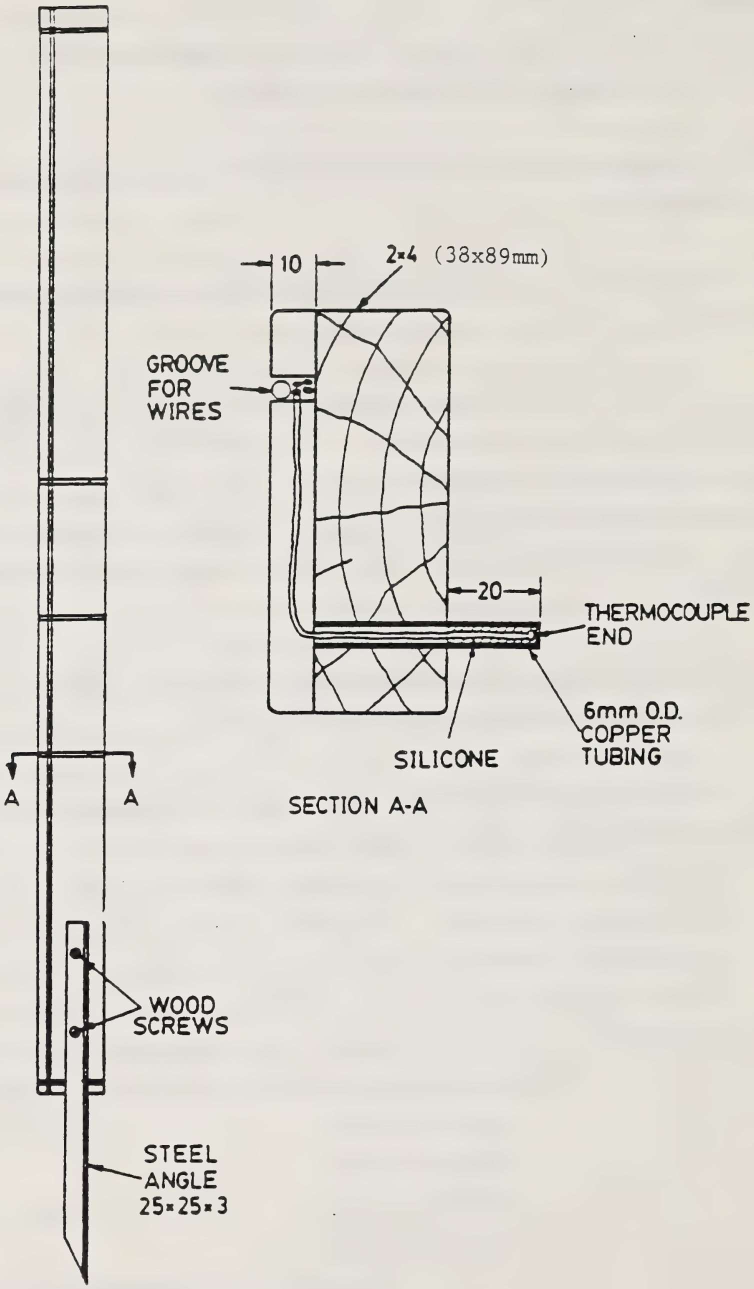


Figure B.1 Detail About Installation of Thermocouples

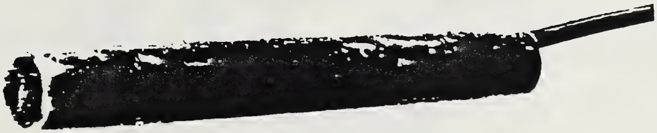


Figure B.2 Thermocouple Embedded in Copper Tube

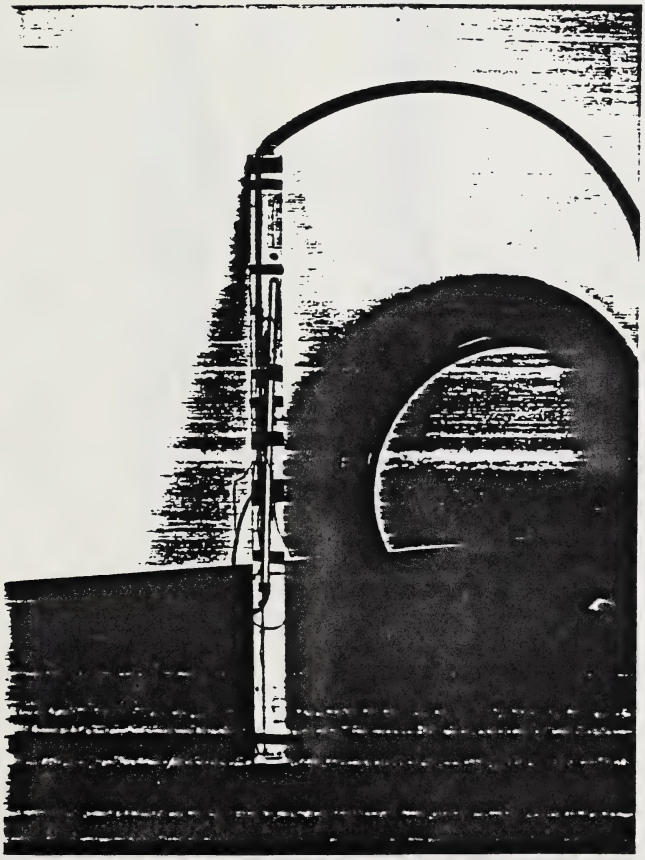


Figure B.3 Assembly of Thermocouples and Thermal Conductivity Probe Ready for Installation

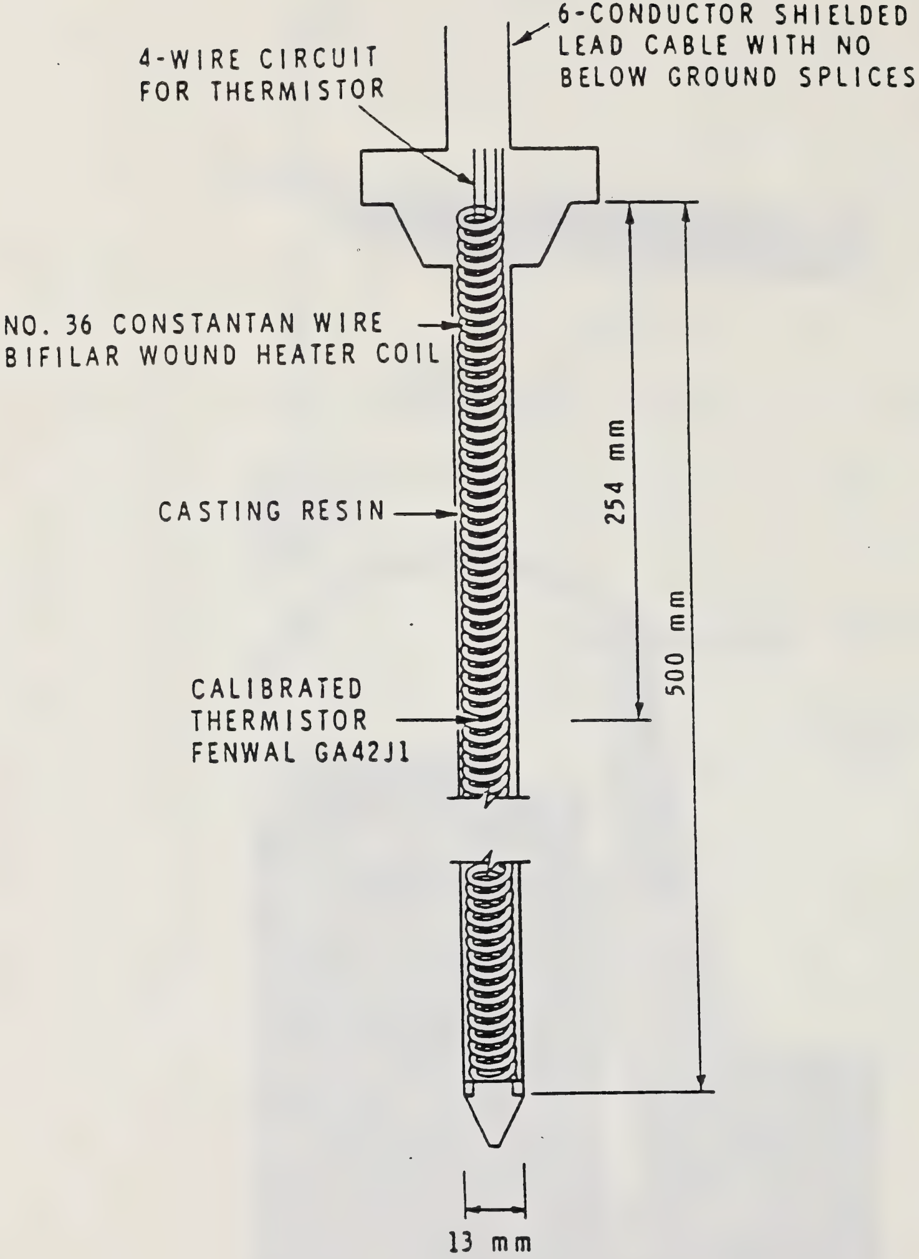
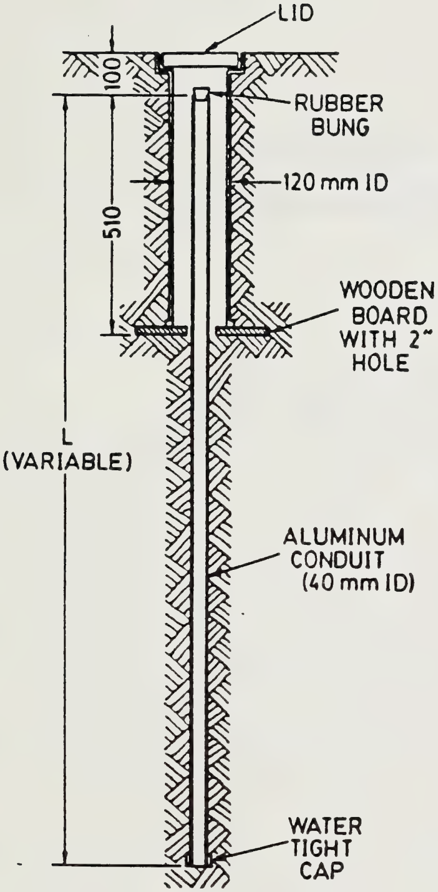

6-CONDUCTOR SHIELDED LEAD CABLE WITH NO BELOW GROUND SPLICES
4-WIRE CIRCUIT FOR THERMISTOR
NO. 36 CONSTANTAN WIRE BIFILAR WOUND HEATER COIL
CASTING RESIN
CALIBRATED THERMISTOR FENWAL GA42J1
254 mm
500 mm
13 mm

Figure B.4 Thermoprobe-Schematic (Fig. from NRC Report)



TEST NO.	LENGTH L (mm)
1	1500
2	1500
3	1500
4	—
5	1700
6	1700
7	—
8	2900
9	1000
10	2900

Figure B.5 Installed Tube for Moisture Content Measurements Complete with Top Box

APPENDIX "C"

MATERIAL PROPERTIES

EXCERPT OF SECTION 4.0
OF THE ORIGINAL STUDY

"FROST PROTECTION OF UNDERGROUND WATER PIPES"

APPENDIX "C"

Excerpts from Original Study
"Frost Protection of Underground Water Pipes"

MATERIAL PROPERTIES:

General

The properties of the Granulite were determined by the National Research Council (NRC) (thermal conductivity) and EBA Engineering Consultants Ltd., (strength, density, freeze-thaw stability, etc.) prior to the field tests. The properties of soil at the test sites were established by Thurber Engineering Ltd. In addition, the mix proportions and design strength of the Insulating Fillcrete used in Test 12 are reported.

Thermal Conductivity of Granulite

The results of the preliminary investigations by NRC are contained in a report by Goodrich and White (Reference 1). In this report the thermal conductivities of expanded shale - Granulite produced by Consolidated Concrete Limited in Calgary and of expanded clay Granulite produced by the same firm in their Edmonton plant are presented. Only the results for the material produced in Calgary and used in the field tests in Calgary are discussed here. The thermal conductivity was first measured at the Calgary Fairview Plant and subsequently several tests were performed in the laboratories of the NRC in Ottawa.

The probes described in Appendix B were used to determine the in-site thermal conductivity of Granulite in three stock piles of material produced at the Calgary facility. The tests were performed by inserting the probes horizontally 750 mm into the stock piles of coarse, medium and fine Granulite. The results for the coarse and medium material used in our tests are summarized in Table C.1. Two values are given for different heater coil power levels. The difference in results is attributed to significant moisture transport away from the probe which results when a large temperature gradient is imposed by the higher input power level. These problems were exacerbated when using small diameter probes such as those available at the time these tests were carried out.

It is to be noted that the results of Table C.1 were obtained on unfrozen material. The results of the laboratory tests for the material produced in Calgary are listed in Table C.2. These tests include samples of frozen (saturated) Granulite.

Other Physical Properties of Granulite

The following tests of expanded shale - Granulite have been performed by EBA Engineering Consultants Ltd., and reported in a document entitled "Report on Laboratory Testing of Lightweight Aggregate, No. 0304-32927-002", dated June 1987 (Reference No. 2):

Grain size distribution
Dry density
One dimensional compression tests
Freeze/thaw stability
Shear strength and bearing capacity
Permeability

The results of the grain size distribution for the medium and coarse Granulite are shown in Figure C.1. The figure shows that over 60% of the medium size Granulite is in the 5 mm to 10 mm range and about 25% in the 10 mm to 12.5 mm range. Almost 80% of the coarse Granulite has a grain size between 12.5 mm and 20 mm.

The density measurement on coarse Granulite showed the following:

maximum dry density - 0.711 Mg/m^3
minimum dry density - 0.663 Mg/m^3

These data indicate that there is only a 7% difference between maximum and minimum density. Strength tests were performed on coarse Granulite only since the coarse Granulite particles are the most porous and for this reason have the lowest strength.

Two one-dimensional compression tests were performed in a 0.3 m x 0.3 m x 0.2 m shear box to establish the compressive strength and the behavior under cyclic loading. It was noticed that audible crushing occurred at stress levels above about 0.40 MPa. Young's modulus, E_v, and the coefficient of volume compressibility, M_v, (expressing the ratio of vertical strain to vertical stress during the one-dimentional compression test) are given in Table C.3. Poisson's ratio is listed to lie between 0.1 and 0.2.

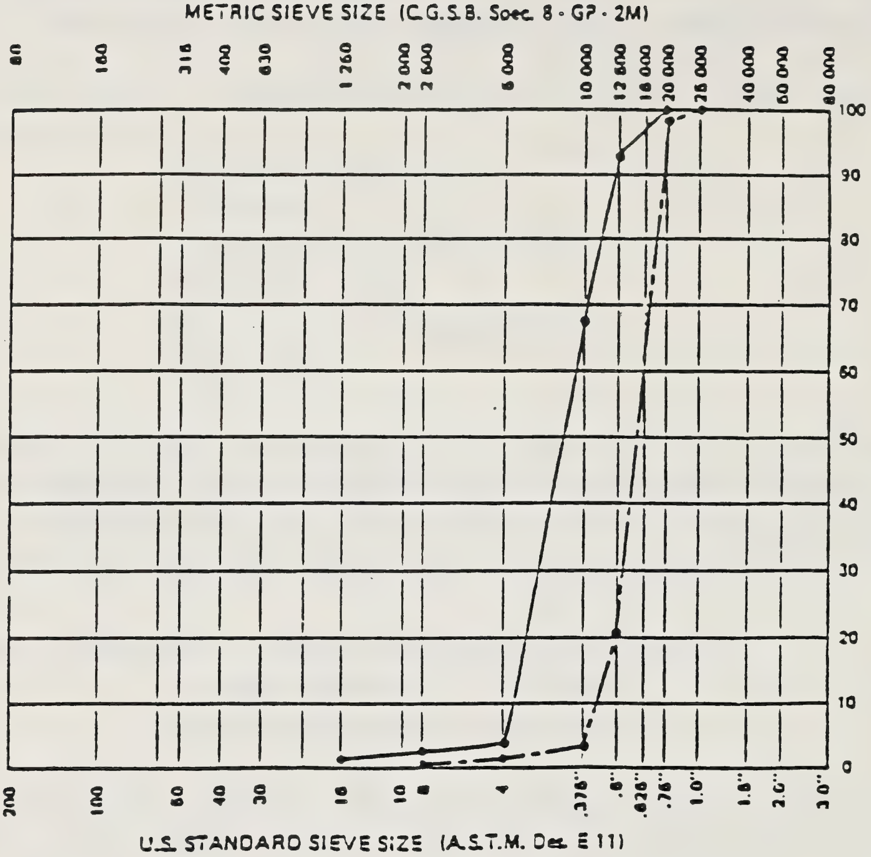


Figure C.1 Grain Size Distribution

—·— COARSE
—— MEDIUM

Upon loading to a stress of 1.0 MPa considerable crushing occurred which is reflected in an increased percentage of fines after the compression test. For this reason, it was recommended to limit the stress level in the Granulite to 0.3 MPa.

The freeze-thaw stability was tested by subjecting a sample, three-fourths submerged in water to 50 freeze/thaw cycles. This rather severe test resulted in a 16.5 percent loss in weight of the 10 mm to 20 mm size aggregate. Under normal conditions no significant breakdown due to freeze-thaw cycles would be expected. The shear strength test resulted in a friction angle in excess of 45° but for design an angle of 40° is recommended. The bearing capacity for footings was also established but this is of no concern for the present research.

Regarding permeability, the report states only that the material is free draining.

Insulating Fillcrete

Insulating Fillcrete was used to backfill the pit of Test 12 from a depth of 1.80 m.

The mix proportions are listed in Table C.4. With this mix a strength of 3.0 MPa was obtained after 28 days.

Natural Soil

1. Manchester Site

   The soil at the Manchester site was classified in a report by Thurber Consultant Ltd., dated October 18, 1988. The results are listed in Table C.5.

2. Forest Lawn Site

   The geotechnical description of the soil at the Forest Lawn site is reproduced in Table C.6.

TABLE C.1

Thermal Conductivity and Moisture Content of Expanded Shale (Unfrozen) Stockpile Tests

FIELD SITE	AGGREGATE SIZE	THERMAL CONDUCTIVITY (W/mK)	POWER (W/M)	MOISTURE CONTENT % WT.
A	Coarse	0.11	0.469	9.3
		0.14	0.154	
B	Medium	0.14	0.469	13.1
		0.17	0.154	

TABLE C.2

Thermal Conductivity of Expanded Shale Laboratory Tests

TEST CONDITION	AGGREGATE SIZE	THERMAL CONDUCTIVITY (W/mK)
Thawed	Medium	0.27 - 0.33
Drained	Coarse	0.20 - 0.23
Thawed	Medium	0.73 - 0.81
Saturated	Coarse	0.64 - 0.74
Frozen	Medium	1.82 - 1.83
Saturated	Coarse	1.20 - 1.25

TABLE C.3

Young's Modulus and Coefficient of Volume Compressibility

CONDITION	E_v (MPa)	M_v (m^2/MN)
Virgin Loading	10 to 20	5 to 10 x 10^{-2}
Unloading/Reloading	100 to 300	3 to 10 x 10^{-3}

TABLE C.4

Mix Proportions of Insulating Fillcrete

Cement	70 kg/m^3
Fly Ash	20 kg/m^3
Water	45 l/m^3
Granulite (Medium)	850 kg/m^3

TABLE C.5

Geotechnical Data for Manchester Test Site

TEST SECTION NO.	DEPTH	DESCRIPTION	MOISTURE CONTENT (BY WEIGHT)
1	1.0 m	GRAVEL sandy, silty	3.9%
1	1.6 m	GRAVEL sandy, silty	5.6 %
9	0.6 m	GRAVEL sandy, silty trace of organics	5.2%

TABLE C.6

Geotechnical Data for the Forest Lawn Test Site

TEST SECTION NO.	DEPTH AND SAMPLE NO.	DESCRIPTION	MOISTURE CONTENT (BY WEIGHT)
12	0.6 m, No. 4, Lake Side	Clay (Till), occasional pebbles and coal specks, hard	11.6%
12	0.6 m, No. 3	Gravel (Fill), silty, sandy, some clay, occasional pieces of asphaltic concrete, odour indicated some contamination with oil or diesel fuel	8.5%
12	1.3 m, No. 2	Clay, (Till), silty, sandy, occasional pebbles, sample was partly wet, ranging in consistency between stiff and soft	13.0%
12	1.8 m, No. 1	Clay, sandy, silty, frequent pebbles, wet, very soft, odour indicated some contamination with oil or diesel fuel	20.3%

N.L.C. - B.N.C.
3 3286 12020228 4